ASSESSING THE WELL-BEING OF GESTATING SUBMISSIVE SOWS IN GROUP PENS USING MULTIPLE WELFARE METRICS

BY

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THESIS

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ABSTRACT

Housing in the swine industry is one of the most controversial issues in animal agriculture today, specifically how to keep gestating sows. Internationally, many countries such as the European Union, Canada, and Australia, as well as some states within the U.S. have banned gestation crates. Consumer and legislative pressure have been the greatest push for these changes, despite studies concluding that group housing and individual gestation crates are both acceptable housing systems with regards to animal welfare. Group housing of sows does allow for social interactions and increased levels of mobility, however the greatest consequence is increased aggression among group-housed sows. The highest level of aggression within a group-pen system occurs during mixing in order to establish social hierarchy and around resources (e.g., water, feeding). Although, aggression is inevitable among group-housed sows in stabilizing social hierarchy, aggression can affect sow productivity and well-being, especially among submissive sows. Therefore, minimizing aggressive encounters using management and dietary strategies may be factors used in a group housing system to improve sow well-being among the submissive sows. The objective of this thesis was to (1) assess the well-being of submissive sows housed in small group pens fed modified gestation diets supplemented with dietary fiber (**MIDDS-HULLS** or **DDGS-GM**) with a competitive feeding system which includes feeding stalls of two different lengths (**LONG** or **SHORT**), and (2) to determine the effect of social status on the stress responsiveness of these sows using multiple welfare metrics. Prior to moving into experimental pens, a feed competition test was used to determine social rank by calculating a dominance value (**DV**) for each sow within a treatment pen, based on aggressive encounters that occurred during the test period. The two sows with the highest DV were identified as dominant (**DOM**) and two sows with the lowest DV were identified as submissive (**SUB**). This

sub sample from a larger study was analyzed separately and used for this thesis (n=64). Sow performance, productivity, behavior, immune and endocrine statuses were assessed throughout gestation to determine sow well-being. Data were analyzed using PROC MIXED with repeated measures and PROC GLIMMIX for ordinal data (SAS). Interactive effects of feeding stall and dietary fiber with social rank were found to affect sow performance, behavior, productivity, and immune status. Socially, SUB sows had greater performance when housed in pens with LONG feeding stalls (social status × stall length; $P < 0.02$) and fed MIDDS-HULLS diet (social status × diet; $P < 0.01$). Aggressive encounters decreased ($P < 0.02$) and socially, SUB sows had greater productivity ($P < 0.01$) when housed in pens with LONG feeding stalls and fed DDGS-GM diet (social status × diet × stall length). Results reported within imply that socially dominant and submissive gestating sows perceive and cope with social stress by evoking different biological responses, and that a combination of management and dietary strategies can improve well-being of submissive sows; therefore, social status should be considered when keeping gestating sows in small group pens using a competitive feeding system.

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Chapter 1: Literature Review

Animal welfare is one of the most contentious issues facing animal agriculture. Particularly for the swine industry, the most controversial issue is how to house gestating sows. Gestating sows can be kept in individual crates or group pens (~5-60 sows/pen) from breeding through gestation until they are relocated to farrowing facilities. Due to consumer and legislative pressure, the swine industry in the United States is transitioning toward alternative group housing systems. Alternative group housing systems have both advantages and disadvantages that are equivalent to individual housing systems in terms of sow welfare. This chapter will discuss animal welfare and the factors that can affect sow well-being as it relates to housing and managing group-kept dry sows.

Animal Welfare

Animal welfare is defined and assessed by different philosophical interpretations throughout the agricultural animal industry. In "Animal Welfare in Animal Agricultural," David Fraser proposes 3 approaches to assessing animal welfare: 'feelings', 'natural behaviors', and 'health' based approaches (Pond et al., 2012). The '*feelings approach'* primarily focuses on the concerns of the animal's "feelings" or "emotions" such as "pleasure," "pain," and "happiness." The '*natural approach'* focuses on the animal's need to display natural behaviors, while minimizing pain and suffering (Rollin, 1993), and providing natural enrichment to encourage natural behaviors. Lastly, the *'health approach'* focuses on animals being free from disease and injury, while providing them with food, water, shelter, and care. Each of these three philosophical approaches encompass at least one of the Five Freedoms, which address the physical fitness and mental suffering of animals:

1. *Freedom from thirst, hunger and malnutrition* – readily access to fresh water and a diet to maintain full health and vigor;
2. *Freedom from discomfort* – providing a suitable environment including shelter and a comfortable resting area;
3. *Freedom from pain, injury and disease* – prevention or rapid diagnosis and treatment;
4. *Freedom to express normal behavior* – providing sufficient space, proper facilities and company of the animal's own kind; and
5. *Freedom from fear and distress* – ensuring conditions which avoid mental suffering.

   (Council, 1993)

Although there are multiple philosophical interpretations of animal welfare, science must be used to help comprehend and clarify the differences in the three interpretations and to focus on elements of each of the freedoms without being anthropomorphic (Pond et al., 2012). For example, research indicates that sows choose to spend less time with their young 10 days post-farrowing, which partly implies that "naturalness" may not be as important to the lactating sows as critics believe (Pond et al., 2012), thus assessing animal welfare using only the "natural" approach may not be beneficial to sow or her offspring. Hence, a single approach nor a single measurement of health, behavior, physiology or performance of any animal does not adequately assess animal well-being, thus a multidisciplinary approach is more beneficial when assessing complex interactions.

Principles of Successful Housing in the Animal Agriculture

The principles of refining successful housing systems should focus on animal welfare, ethics, economics, and sustainability. These principles cannot be independent of each other; therefore a good approach may be the Ethical Matrix proposed by Mepham (1996; Figure 1.1).

The Ethical Matrix

Respect for	*Wellbeing (health and welfare)*	*Autonomy (freedom/choice)*	*Justice (fairness)*
Treated organisms	Animal welfare	*telos*	Duty of care
Producers	Farmer welfare	Freedom to adopt or not	Fair treatment in trade and law
Consumers	Availability of safe food	Choice and labelling	Affordability of food
Living environment	Conservation	Biodiversity	Sustainability of populations

Figure 1.1 The ethical matrix of food production (Mepham, 1996)

The matrix begins with animal welfare and defines the responsibilities of producers and consumers to the animals, which is to provide appropriate care that meets their needs based on scientific research. Consumer awareness and demand for improved animal welfare of food animals is primarily due to the pressure from animal rights groups, which has led to a demand for "natural foods" and more-welfare friendly products. Despite these demands, consumers must understand that these changes not only affect the animal, but the producer, industry, and society as a whole. For example, eliminating the use of the gestation crates results in an increased economic cost to the producer of 5% which is equivalent to a retail increase of $1.19-1.30 (McInerney, 1998). The economic cost is mainly attributed to the additional space needed to transition from individual gestation crates to group-pens as well as the additional animal care cost that may be required to treat injuries due to an increase in aggression among group-housed sows. A successful housing system needs to take into consideration animals, producers, consumers, and environment, while emphasizing animal welfare.

Stress & Animal Welfare

The concept of stress physiology began with the works of Hans Selye and Walter Cannon. Both described stress as physiological response to a specific stressor and the consequences of stress were due to hormones secreted from the adrenal medulla (epinephrine)

and cortex (glucocorticoids, GC) (Levine, 2005). More specifically, Cannon emphasized the physiological responses initiated to maintain the body's internal milieu—coined the term homeostasis—while Selye emphasized a trio of responses which included the endocrine, autonomic, and immune systems in attempt of an organism to adapt (Levine, 2005). There is much debate about which of these two icons defined "stress", but Selye is often given credit and is referred to as the "father of stress physiology."

Moberg (2000) defines stress as "the biological response elicited when an individual organism perceives a threat to its homeostasis", whereas, McEwen (2000) further defines stress to include "either a real or interpreted threat to the physiological or psychological integrity of an individual that results in physiological and behavioral responses". Moreover, Curtis (2009) defined stress as "resulting from an animal's failure to adapt to challenging environmental conditions, thus reducing an animal's fitness". Despite numerous definitions, it is clear that unless the stressor is mitigated, the biological consequences of stress inevitably can lead to harm and even death of the animal. In short, stressors disrupt the stability of an animal's internal milieu (homeostasis) either acutely or chronically and if the animal does not successfully return to normal biological function this can result in negative consequences on its well-being.

The process of maintaining equilibrium by whole-body physiological and or behavioral regulation under stress is known as allostasis (Sterling and Eyer, 1988; Schulkin, 2004).The maintenance of allostasis requires activation of complex responses of one or combination of behavioral, autonomic, neuroendocrine and immune systems, known as the stress response. The stress response is dependent on the type of stressor, duration, short-term versus long-term/chronic stress, and physiological state. Stress can be positive or negative as it is a nonspecific response of the body by any stressor that may cause pleasure or pain. Therefore, not

all stress is negative and depends on the animal's biological state and perception of a stressor to be able to adapt or cope with the threat. Specifically for gestating sows, her pregnancy will influence how she perceives environmental, physiological, and social stressors, and will try to adapt to these stressors differently than a non-pregnant sow or a juvenile female (Moberg and Mench, 2000). Inappropriate or lack of regulation of the stress response may lead to illness and/or decrease in reproduction.

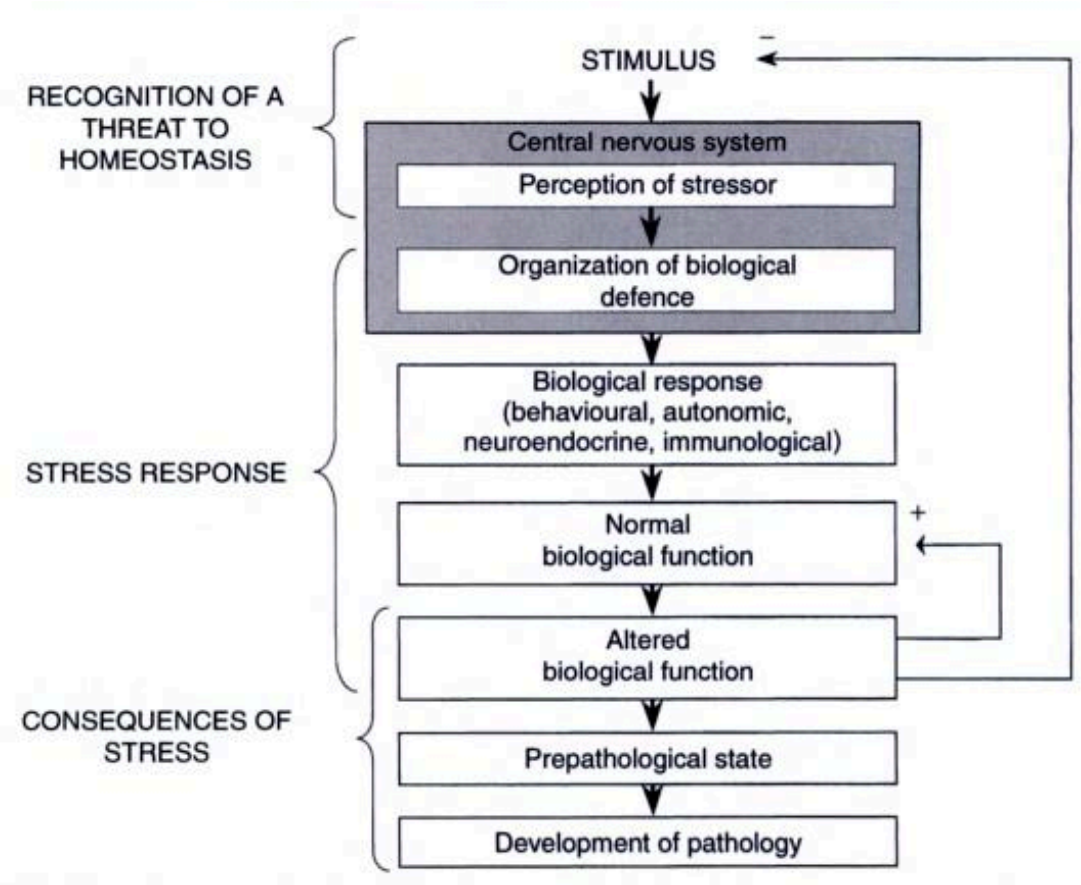

Figure 1.2 A model of the biological response of animals to stress (Moberg, 1987)

Moberg (1987; 2000) illustrates the biological stress response of animals (refer to figure 1.2) in 3 stages: (**1**) the recognition of a threat to homeostasis, (**2**) the stress response, and (**3**) the consequences of stress. The biological response to stress begins within the central nervous

system (CNS) with the recognition and organization of the response to the threat—it is important to note that the threat can be real or perceived and psychological or physical. An animal's perception of a threat can be affected by genetics, previous experience, age, and physiological state of the animal. Once the stimulus is perceived as a threat, the animal initiates the most appropriate biological response in attempt to mitigate or eliminate the threat. The biological response can be behavioral, autonomic nervous system, neuroendocrine, and/or immune (Moberg and Mench, 2000). The final stage is the consequences of stress, this determines if the animal's well-being is significantly hindered or not.

A behavioral response is often the first response initiated by an animal in its attempt to cope with the threat because it is the fastest and most economical response available. However, a behavioral response may not be appropriate for all stressors especially when situations are limited (e.g., confinement), but for the most part a behavioral response is still part of every stress response. The most common stress-related behavioral responses include re-directed, displacement, and stereotypic behaviors. Re-directed behaviors often provide a behavioral outlet toward an inappropriate stimulus, while displacement behaviors are considered to be irrelevant to the situation, and stereotypic behaviors are repetitive patterns of activity with no apparent purpose, thus are indicative of poor welfare. Other behaviors that are considered to be indicative of coping difficulty include: reduced appetite, irregular movement, increased aggression, restlessness, or unusual vocalizations. Behavioral responses to stressors are highly dependent on animal characteristics and are a "clue" to an animal's ability to cope with an acute stressor, but the understanding and interpretation of behavioral repertoire is difficult.

The autonomic nervous system (ANS) consists of two branches: the sympathetic nervous system (SNS) and the parasympathetic nervous system (PSN), both resulting from the autonomic

response to stress. The SNS activates the flight-or-fight response which results in an increase in blood flow, release of stored glucose and lipids and other metabolites, as well as the release of catecholamines, which include both epinephrine and norepinephrine. The PSN stimulates a "rest and digest" response by conserving energy and releasing digestive enzymes. Another biological response to stress is activation of the neuroendocrine system. The neuroendocrine response involves activation of the CNS, specifically the hypothalamic-pituitary-adrenal response (HPA) and thyroid axes in certain situations. The HPA axis along with several other structures play important roles in the regulation of adaptive response to stress (Smith and Vale, 2006). Activation of the HPA begins in the paraventricular nucleus (PVN) of the hypothalamus with the release of corticotropin releasing factor (CRF), then the release of adrenocorticotropic hormone (ACTH) from the anterior pituitary gland, and finally the release of glucocorticoids (primarily cortisol) from the adrenal cortex and catecholamines from the adrenal medulla. Epinephrine and norepinephrine are released especially in a fight-flight situation and have been shown to affect carbohydrate metabolism and blood glucose levels. These hormones play a role in the breakdown of carbohydrates and lipids into useable glucose for energy through the process of gluconeogenesis. Under normal conditions, glucose enters the bloodstream and insulin is produced to aid cells in absorbing the energy, which then reduces the level of blood glucose. This absorbed energy can help in the flight-fight response but during long-term stress the elevated hormone levels result in elevated production of glucose. Furthermore, high levels of cortisol can create insulin resistant fat and muscle cells, which may also result in elevated levels of glucose.

Stressors can positively, negatively, or have no effect on the immune status of an animal (Salak-Johnson and McGlone, 2007). Mechanisms of immune-enhancement or suppression may

result in changes in maturation and function of various cell types including dendritic cells, neutrophils, macrophages, and lymphocytes as well as the production of cytokines (Dhabhar, 2014). Acute stress results in an increase in neutrophils, decrease in lymphocytes, T and B-lymphocytes and natural killer cell cytotoxicity suppression. In contrast, long-term stress suppresses or deregulates innate and adaptive immune responses, such as Type 1-Type 2 cytokine balance, inflammation, and functionality of immune cells (Dhabhar, 2014). Therefore, assessing both innate and adaptive immune response is essential to understanding the impact of stressors on animal well-being, as individual animals within a group respond differently to stressors and disease challenges.

Evaluating an animal's stress response is a great tool for measuring their well-being by using behavioral and physiological measurements, along with performance and productivity to help determine consequences on an animal that is unable to cope or adapt to its' environment. Science will allow us to distinguish which management strategy can be detrimental to animal's well-being in agriculture.

Factors that Impact Animal Welfare

Many factors within a group housing system can affect the well-being of the gestating sow such as feeding system, space allowance, social status, and nutrition. Some of these factors may evoke a stress response and ultimately impact sow performance, behavior, physiology, and productivity if sow has difficulty coping and adapting to her environment.

Housing Management:

Feeding System. Feeding systems may be classified as either competitive or non-competitive/individual. These different feeding systems ultimately impact the level of aggression

displayed among sows during feeding. A non-competitive/individual feeding system allows sows to eat their daily feed allocation without interference from other sows. Conversely, when sows are feed using a competitive feeding systems there is more aggressive encounters during feeding because sows can disrupt other sows feeding bouts, which often results in variable body condition scores among the group. Feeding systems can further be classified as simultaneous or asynchronous. Options for group housing feeding system with simultaneous and competitive feeding are floor feeding, feeding stalls/barriers, and trickle feeding. A simultaneous feeding system that is non-competitive/individual is the free access feeding system (lockable stalls with the option of a group pen area). A group housing option with asynchronous feeding system is an electronic sow feeder (ESF), which allows one sow into the feeder at a time.

The simplest competitive/simultaneous feeding systems used is either floor feeding and/or feeding stalls, which often result in increased aggression and variability in body condition because of variability in feed intake. Andersen et al. (1999) found that sows kept in pens fitted with full-body length feeding stalls engaged in less acts of aggression and displacements at the feeding trough compared to sows in pens with shoulder-length or no feeding stalls; however, sows housed in pens with full-body length feeding stalls had more vulva bites. Conversely, sows housed in pens with ESF feeding system engaged in more fights, but fewer total agonistic interactions than did those sows that were kept in small groups of 5 in pens with feeding stalls (Broom et al., 1995). In another study, sows housed in group pens with Fitmix (ESF without protective feeding crate) feeding system had greater frequency of aggressive interactions around the feeder than did those in pens with trickle feeding system, but there were no differences in vulva injury scores and reproductive efficiency between treatment groups (Chapinal et al., 2010). On the contrary, other studies have shown that feeding systems affect sow behavior and skin

lesion scores (Broom et al., 1995; Andersen et al., 1999). While aggression cannot be eliminated in group pen systems during feeding, the use of feeding stalls can partly reduce aggression among sows within the pen (Andersen et al., 1999; O'Connell et al., 2003). Therefore, the use of feeding stalls in small groups may allow sows to feed simultaneously while providing some protection, and may result in increased feed intake and reduced variability in BCS.

Space Allowance. The amount of floor-space allowance within a group pen is an important factor that must be considered, especially in terms of minimizing aggression and providing sows the opportunity to avoid or escape overly-aggressive sows. Sows housed in group pens at a floor-space allowances of 3.0 m^2/sow with an ESF feeding system had less severe injuries than did sows kept at 2.25 m^2 of floor-space, but productivity and aggressive encounters at mixing were similar between treatment groups (Remience et al., 2008). Salak-Johnson et al. (2007) found that sows kept at floor-space allowance of $\geq$ 2.3 m^2 had greater BW and BF depth, and that sows kept at 3.3 m^2 had larger litters. Sow BCS was reduced and skin lesion score increased for sows kept in pens at 1.4 m^2 of floor-space compared with sows kept at floor-space of $\geq$ 2.3 m^2 (Salak-Johnson et al., 2007). Hemsworth et al. (2013) found as floor-space allowance increased from 1.4 to 3.0 m^2/sow farrowing rate increased.

Floor space allowance may also affect sow behavior and physiology. Sows kept in pens at 2.3 m^2 performed more ONF, stand, and drink behaviors, whereas, sows kept at 1.4 m^2 performed more sham-chew behavior (Salak-Johnson et al., 2012). Mack et al. (2014) found that the amount of floor-space allowance available in the group-pen area of the free access stall system affected the amount of time sows spent in the pen-area; sows kept at 1.9 m^2 of floor-space used the group-pen space less than did sows at either 2.68 m^2 or 3.24 m^2 of floor-space. Moreover, as floor-space decreased, neutrophils, neutrophil-to-lymphocyte ratio, and natural

killer cell cytotoxicity increased, but lymphocyte proliferation decreased (Salak-Johnson et al., 2012). Aggression and injuries were also affected by floor-space allowance, as space allowance increased from 1.4 to 4.8 m^2 /sow aggression decreased throughout gestation (Weng et al., 1998; Remience et al., 2008; Hemsworth et al., 2013). Floor-space allowance and feeding system both contribute to the level of aggression within a group pen system.

***Social Status*.** Social hierarchy among sows is established through aggressive encounters that occur within the first couple of days post-mixing. In general, aggression and injuries decrease once social hierarchy is established within a group of sows (Beilharz and Cox, 1967). However, social status of individual sows has been shown to affect behavior, physiology, performance, and productivity. Submissive (lower-ranked or subordinate) sows receive more aggressive encounters and are displaced more often from the feeder than dominant (higher-ranked) sows, which results in lower feed intake among submissive sows (Andersen et al., 1999; O'Connell et al., 2003). Similarly, dominant sows are more active and aggressive than submissive sows, and displace submissive sows more often from gaining access to enrichment materials (Elmore et al., 2011). Total time spent feeding was similar regardless of social rank, but dominant sows displace submissive sows during feeding more often causing submissive sows to retreat and experience prolonged periods of no eating (Csermely and Wood‐Gush, 1990). Forty-six percent of sows (primarily submissive sows) housed in pens with a Fitmix feeding system needed assistance to adapt to feeder with 8.3% of these sows failing to adapt (Chapinal et al., 2010).

Social status is positively correlated with sow BW and parity (Arey, 1999; Chapinal et al., 2010). Submissive sows have lower BW and/or higher levels of body lesions or injuries than dominant sows (O'Connell et al., 2003; Tönepöhl et al., 2013; Zhao et al., 2013). Others found

that submissive sows have lower farrowing rates (Hoy et al., 2009; Zhao et al., 2013) and less total born (Hoy et al., 2009; Tönepöhl et al., 2013); while Zhao et al. (2013) found that dominant sows had lower number of piglets born alive, lower litter weights and increased number of stillborn. Still, others have found no effect of sow social status on productivity (Arey, 1999; Chapinal et al., 2010).

Studies are limited on the effects of social rank on physiology of sows. O'Connell et al. (2003) found no effect of social status on cortisol in sows, but Sutherland et al. (2006) found that young dominant pigs had greater total white blood cell count, NK cytotoxicity, and neutrophil phagocytosis than did young submissive pigs. At 12-wk-of-age, dominant pigs had greater lymphocyte proliferation than did submissive pigs, but cortisol was similar (Tuchscherer et al., 1998). Dominant animals have been shown to have enhanced immune activation where submissive animals have suppressed immune activation, but a better understanding of the consequences and interactions between social and environmental stressors for innate and adaptive responses needs to be further developed (Salak-Johnson and McGlone, 2007).

Taken together, these studies imply that social status needs to be taken into consideration when mixing sows due to the significant effects on the sow behavior and productivity, which can impact sow well-being. Moreover, some research indicates that submissive sows may need more time to adapt to some of the feeding systems and if they cannot adapt and/or do not consume sufficient amounts of feed, well-being is compromised. There also needs to be more research investigating physiology differences in sows based on social status as the swine industry is moving towards group housing and is necessary to get a better understanding of an animal's welfare.

Other. Dynamic (continuously adding new sows to already established group) versus static (no addition of sows) groups may have an effect on stress levels due to increased aggressive interactions. Anil et al. (2006) found that although skin lesions were higher in groups of sows managed dynamically, there were no differences on the total number of aggressive interactions, cortisol levels, and farrowing rate compared to those sows that were managed in static groups. Similarly, Li and Gonyou (2013) reported no differences in farrowing rate, however sows managed in dynamic groups did have higher skin lesion scores and incidences of lameness than did sows managed in static groups. Consequently, studies have shown that when sows are managed in dynamic groups they tend to have higher skin lesions and injuries than sows managed in static groups, which can affect their well-being.

Day of mixing post-breeding is another factor that must be considered when managing sows in groups. Strawford et al. (2008) found that sows that were mixed at d 37 post-breeding were less aggressive than were sows mixed at d 46. Lameness and skin lesions increased among mixing and number of fights were less 24-h post-mixing for sows grouped at d14 post-breeding compared with those that were mixed at d 3 and 35 post-breeding (Knox et al., 2014). Also, sows that were mixed at d 3 post-breeding had lower conception and farrowing rates when housed in large group pens that were equipped with an ESF feeding system compared with those sows were mixed at d 14 and 35 post-breeding (Knox et al., 2014). These studies indicate the appropriate day to mix sows post-breeding into group pens may be between d 14 and d 37 post breeding when kept in larger groups equipped with an ESF feeding system.

Dietary Management:

Gestating sows are fed a restricted diet based on metabolizable energy (6,700 kcal ME/day/sow first 90 d, 10,720 kcal ME/day/sow d 90 to d 105) to minimize reduced productivity, but diets are formulated to meet their maintenance and reproductive needs (NRC, 2012). It has been shown that when sows are feed-restricted they develop stereotypies which increases sow activity levels and may be the expression of high levels of motivation to feed or forage (Terlouw et al., 1991; Terlouw and Lawrence, 1993; Terlouw et al., 1993). Therefore, diet has an effect on sow's behavior, performance, productivity, and overall well-being.

High Fiber. One of the major drawbacks of group housing is the aggression that occurs at mixing and around feeding. Feeding high fiber gestation diets is a potential dietary management strategy that may be used to improve sow satiety, aggression, and well being. Dietary fiber increases the daily feed allowance without increasing energy intake and controls BW gain (Johnston, 2010). High fiber ingredients may include oat hulls, straw, sugar beet pulp, and wheat bran. Souza de Silva et al. (2012) found that sows feed a soluble diet had greater feeding motivation than did sows fed a bulky or highly fermentable fiber. Conversely, Leeuw et al. (2005) found no differences in behavioral measurements when sows were fed a mixture of high fiber sources versus sugar beet pulp. Sows and gilts kept in group pens and fed high fiber diets spend more time eating, less active, and engaged in less oral behaviors and stereotypies than did those animals fed a control diet (Robert et al., 1993; Brouns et al., 1994; de Leeuw et al., 2004; de Leeuw et al., 2005). Others, have found no effect on stereotypic behaviors among sows fed high fiber diets (Whittaker et al., 1998; Whittaker et al., 1999; Holt et al., 2006). As for aggression, Whittaker et al. (1999) found that floor feeding a high fiber diet to sows in groups does not affect aggression during feeding, while Danielsen and Vestergaard (2001) reported that

feeding high-fiber diets reduces aggression and sham chewing among gilts kept in small group pens. Holt et al. (2006) found sows gained less BW and BF when fed a high fiber diet, while others found no differences in BW and BF among sows fed high fiber diets (de Leeuw et al., 2005; Guillemet et al., 2007; Quesnel et al., 2009). In regards to performance and productivity, McGlone and Fullwood (2001) found gilts fed high fiber had greater pre-farrowing and weaned weights, but no difference in number of pigs born alive and pre-weaning mortality as did Matte et al. (1994) and Guilletmet et al. (2007). Although Matte et al. (1994) and Guilletmet et al. (2007) found no significant effects on number of piglets born alive, they both discovered sows fed high fiber diets had heavier piglets and Quesnel et al. (2009) found piglets grew faster than piglets from sows fed control diets. High fiber diets to gestating sows have also been shown to stabilize glucose and insulin levels.

There are many contradicting studies containing the feeding of high fiber diets to sows and gilts in group housing, which indicates the need for further research to provide clarity on the effects on stereotypies, aggression, BW, feeding motivation, and productivity.

Literature Cited

Andersen, I. L., K. E. Bøe, and A. L. Kristiansen. 1999. The influence of different feeding arrangements and food type on competition at feeding in pregnant sows. Applied Animal Behaviour Science 65: 91-104.

Anil, L., S. S. Anil, J. Deen, S. K. Baidoo, and R. D. Walker. 2006. Effect of group size and structure on the welfare and performance of pregnant sows in pens with electronic sow feeders. Canadian Journal of Veterinary Research 70: 128-136.

Arey, D. S. 1999. Time course for the formation and disruption of social organisation in group-housed sows. Applied Animal Behaviour Science 62: 199-207.

Beilharz, R. G., and D. F. Cox. 1967. Social dominance in swine. Animal Behaviour 15: 117-122.

Broom, D. M., M. T. Mendl, and A. J. Zanella. 1995. A comparison of the welfare of sows in different housing conditions. Animal Science 61: 369-385.

Brouns, F., S. A. Edwards, and P. R. English. 1994. Effect of dietary fibre and feeding system on activity and oral behaviour of group housed gilts. Applied Animal Behaviour Science 39: 215-223.

Chapinal, N. et al., 2010. Aggressive Behavior in Two Different Group-Housing Systems for Pregnant Sows. Journal of Applied Animal Welfare Science 13: 137-153.

Council, F. A. W. 1993. Second Report on Priorities for Research and Development in Farm Animal Welfare. FAWC, Ministry of Agricultural, Fisheries and Food, Tolworth (Now DEFRA, London).

Csermely, D., and D. G. M. Wood‐Gush. 1990. Agonistic behaviour in grouped sows. II. How social rank affects feeding and drinking behaviour. Bolletino di zoologia 57: 55-58.

Curtis, S. E. 2009. Environmental Aspects of Animal Care: Applied Ecology in the Husbandry of Kept Animals. 1: 81-85.

da Silva, C. S., J. J. van den Borne, W. J. Gerrits, B. Kemp, and J. E. Bolhuis. 2012. Effects of dietary fibers with different physicochemical properties on feeding motivation in adult female pigs. Physiology & behavior 107: 218-230.

Danielsen, V., and E.-M. Vestergaard. 2001. Dietary fibre for pregnant sows: effect on performance and behaviour. Animal Feed Science and Technology 90: 71-80.

de Leeuw, J. A., A. W. Jongbloed, and M. W. A. Verstegen. 2004. Dietary Fiber Stabilizes Blood Glucose and Insulin Levels and Reduces Physical Activity in Sows (Sus scrofa). Journal of Nutrition 134: 1481-1486.

de Leeuw, J. A. et al., 2005. Effects of levels and sources of dietary fermentable non-starch polysaccharides on blood glucose stability and behaviour of group-housed pregnant gilts. Applied Animal Behaviour Science 94: 15-29.

Dhabhar, F. S. 2014. Effects of stress on immune function: the good, the bad, and the beautiful. Immunologic research 58: 193-210.

Elmore, M. R. P. et al., 2011. Getting around social status: Motivation and enrichment use of dominant and subordinate sows in a group setting. Applied Animal Behaviour Science 133: 154-163.

Guillemet, R. et al., 2007. Dietary fibre for gestating sows: effects on parturition progress, behaviour, litter and sow performance. animal 1: 872-880.

Hemsworth, P. H. et al., 2013. Effects of group size and floor space allowance on grouped sows: Aggression, stress, skin injuries, and reproductive performance. Journal of Animal Science 91: 4953-4964.

Holt, J. P., L. J. Johnston, S. K. Baidoo, and G. C. Shurson. 2006. Effects of a high-fiber diet and frequent feeding on behavior, reproductive performance, and nutrient digestibility in gestating sows. Journal of Animal Science 84: 946-955.

Hoy, S., J. Bauer, C. Borberg, L. Chonsch, and C. Weirich. 2009. Impact of rank position on fertility of sows. Livestock Science 126: 69-72.

Johnston, L. 2010. Gestating Swine Nutrient Recommendations and Feeding Management.

Knox, R., J. Salak-Johnson, M. Hopgood, L. Greiner, and J. Connor. 2014. Effect of day of mixing gestating sows on measures of reproductive performance and animal welfare. Journal of Animal Science 92: 1696-1705.

Levine, S. 2005. Chapter 1.1 - Stress: an historical perspective. In: N. H. K. T. Steckler and J. M. H. M. Reul (eds.) Techniques in the Behavioral and Neural Sciences No. Volume 15, Part 1. p 3-23. Elsevier.

Li, Y., and H. Gonyou. 2013. Comparison of management options for sows kept in pens with electronic feeding stations. Canadian Journal of Animal Science 93: 445-452.

Mack, L. A. et al., 2014. Group space allowance has little effect on sow health, productivity, or welfare in a free-access stall system. Journal of Animal Science 92: 2554-2567.

Matte, J. J., S. Robert, C. L. Girard, C. Farmer, and G. P. Martineau. 1994. Effect of bulky diets based on wheat bran or oat hulls on reproductive performance of sows during their first two parities. Journal of animal science 72: 1754-1760.

McEwen, B. S. 2000. Stress, definition and concepts of. Encyclopedia of stress 3: 508-509.

McGlone, J., and S. Fullwood. 2001. Behavior, reproduction, and immunity of crated pregnant gilts: effects of high dietary fiber and rearing environment. JOURNAL OF ANIMAL SCIENCE-MENASHA THEN ALBANY THEN CHAMPAIGN ILLINOIS- 79: 1466-1474.

McInerney, J. 1998. The economics of Welfare.

Mepham, B. 1996. Ethical Analysis of Food Biotechnologies: an Evaluative Framework. Food Ethics: 101-119.

Moberg, G. 1987. Problems in defining stress and distress in animals. Journal of the American Veterinary Medical Association 191: 1207-1211.

Moberg, G. P., and J. A. Mench. 2000. The biology of animal stress: basic principles and implications for animal welfare. CABI.

NRC. 2012. Nutrient Requirements of Swine: Eleventh Revised Edition, Washington, DC.

O'Connell, N. E., V. E. Beattie, and B. W. Moss. 2003. Influence of social status on the welfare of sows in static and dynamic groups. Animal Welfare 12: 239-249.

Parent, J.-P., M.-C. Meunier-Salaün, E. Vasseur, and R. Bergeron. 2012. Stability of social hierarchy in growing female pigs and pregnant sows. Applied Animal Behaviour Science 142: 1-10.

Pond, W. G., F. W. Bazer, and B. E. Rollin. 2012. Animal welfare in animal agriculture : husbandry, stewardship, and sustainability in animal production. CRC Press, Boca Raton, FL.

Quesnel, H. et al. 2009. Dietary fiber for pregnant sows: Influence on sow physiology and performance during lactation. Journal of Animal Science 87: 532-543.

Remience, V. et al. 2008. Effects of space allowance on the welfare of dry sows kept in dynamic groups and fed with an electronic sow feeder. Applied Animal Behaviour Science 112: 284-296.

Robert, S., J. J. Matte, C. Farmer, C. L. Girard, and G. P. Martineau. 1993. High-fibre diets for sows: effects on stereotypies and adjunctive drinking. Applied Animal Behaviour Science 37: 297-309.

Rollin, B. E. 1993. Animal welfare, science, and value. Journal of Agricultural and Environmental Ethics 1993.

Salak-Johnson, J. L., A. E. DeDecker, M. J. Horsman, and S. L. Rodriguez-Zas. 2012. Space allowance for gestating sows in pens: Behavior and immunity. Journal of Animal Science 90: 3232-3242.

Salak-Johnson, J. L., and J. J. McGlone. 2007. Making sense of apparently conflicting data: Stress and immunity in swine and cattle. Journal of Animal Science 85: E81-E88.

Salak-Johnson, J. L., S. R. Niekamp, S. L. Rodriguez-Zas, M. Ellis, and S. E. Curtis. 2007. Space allowance for dry, pregnant sows in pens: Body condition, skin lesions, and performance. Journal of Animal Science 85: 1758-1769.

Schulkin, J. 2004. Allostasis, homeostasis and the costs of physiological adaptation. Cambridge University Press, Cambridge UK ; New York.

Smith, S. M., and W. W. Vale. 2006. The role of the hypothalamic-pituitary-adrenal axis in neuroendocrine responses to stress. Dialogues in clinical neuroscience 8: 383.

Sterling, P., and J. Eyer. 1988. Allostasis: a new paradigm to explain arousal pathology.

Strawford, M. L., Y. Z. Li, and H. W. Gonyou. 2008. The effect of management strategies and parity on the behaviour and physiology of gestating sows housed in an electronic sow feeding system. Canadian Journal of Animal Science 88: 559-567.

Sutherland, M. A., S. R. Niekamp, S. L. Rodriguez-Zas, and J. L. Salak-Johnson. 2006. Impacts of chronic stress and social status on various physiological and performance measures in pigs of different breeds. Journal of Animal Science 84: 588-596.

Terlouw, E. M. C., and A. B. Lawrence. 1993. Long-term effects of food allowance and housing on development of stereotypies in pigs. Applied Animal Behaviour Science 38: 103-126.

Terlouw, E. M. C., A. B. Lawrence, and A. W. Illius. 1991. Influences of feeding level and physical restriction on development of stereotypies in sows. Animal Behaviour 42: 981-991.

Terlouw, E. M. C., A. B. Lawrence, J. M. Koolhaas, and M. Cockram. 1993. Relationship between feeding, stereotypies, and plasma glucose concentrations in food-restricted and restrained sows. Physiology and Behavior 54: 189-193.

Tönepöhl, B., A. K. Appel, B. Voß, U. König von Borstel, and M. Gauly. 2013. Interaction between sows' aggressiveness post mixing and skin lesions recorded several weeks later. Applied Animal Behaviour Science 144: 108-115.

Tuchscherer, M., B. Puppe, A. Tuchscherer, and E. Kanitz. 1998. Effects of social status after mixing on immune, metabolic, and endocrine responses in pigs. Physiology & Behavior 64: 353-360.

Weng, R. C., S. A. Edwards, and P. R. English. 1998. Behaviour, social interactions and lesion scores of group-housed sows in relation to floor space allowance. Applied Animal Behaviour Science 59: 307-316.

Whittaker, X., S. Edwards, H. Spoolder, A. Lawrence, and S. Corning. 1999. Effects of straw bedding and high fibre diets on the behaviour of floor fed group-housed sows. Applied Animal Behaviour Science 63: 25-39.

Whittaker, X., H. Spoolder, S. Edwards, A. Lawrence, and S. Corning. 1998. The influence of dietary fibre and the provision of straw on the development of stereotypic behaviour in food restricted pregnant sows. Applied Animal Behaviour Science 61: 89-102.

Zhao, Y., W. L. Flowers, A. Saraiva, K. J. Yeum, and S. W. Kim. 2013. Effect of social ranks and gestation housing systems on oxidative stress status, reproductive performance, and immune status of sows. Journal of Animal Science 91: 5848-5858.

Chapter 2.

Dietary fiber and feeding stall length affects the well-being of gestating submissive sows in small group pens

ABSTRACT

The effects of high-fiber gestation diets and length of feeding stall on well-being of submissive sows housed in small group pens was evaluated using multiple welfare measures. At gestational d 37, groups of 9 multiparous sows/pen (n = 144 total sows; n = 36 sows/block) were randomly assigned by BW and parity to a 2 x 2 factorial arrangement of dietary treatment of either (**a**) soy hulls-wheat middlings diet (MIDDS-HULLS) or (**b**) DDGS-corn germ meal diet (DDGS-GM), and to a feeding stall length of either (**c**) 0.6 m (SHORT) or (**d**) 1.8 m (LONG). To determine social rank sows were subjected to a feed competition test; within each treatment pen a dominance value (DV) was calculated for each sow based on aggressive encounters during a feeding competition test. The two sows with the highest DV were identified as dominant (DOM) and the two with the lowest DV were identified as submissive (SUB), this subpopulation of sows was used for analysis (n = 64). Sow BW, backfat (BF), body condition score (BCS) and blood samples were obtained on gestational d 30, 70, 90, 104, and d 131 (end of lactation). Body lesion scores and blood glucose levels (along with sow behavior) were recorded every 3 d for 2-wks post mixing (Phase 1), and then again on a bi-weekly basis until gestational d 104 (Phase 2). Live behavioral observations during feedings were registered at feeding post-mixing (d38), and then every 3-wk until gestational d 104, all aggressive encounters were recorded. SUB sows were heaviest when housed in pens with LONG feeding stalls than with SHORT feeding stalls (social status × stall length; $P < 0.02$) and SUB sows were heaviest when fed MIDDS-HULLS diet than DDGS-GM and had similar performance as DOM sows (social status x diet; $P < 0.01$). Total aggressive encounters (AE; $P < 0.02$) and no. of AE towards SUB sows was lowest ($P < 0.004$) for those sows housed in pens with LONG and fed DDGS-GM (diet × stall length). Stand and sit behaviors were greatest ($P < 0.02$) for SUB sows fed DDGS-GM, but time spent eating was highest ($P < 0.004$) among SUB sows fed MIDDS-HULLS diet. Piglets born to SUB sows in pens with LONG and fed DDGS-GM diet had the heaviest adjusted litter ($P < 0.01$) and piglet wean BW ($P < 0.005$) (social status × diet × stall length). These results imply that it is plausible to improve SUB sows well-being if housed in small group pens with long feeding stalls and fed a modified high fiber diet of DDGS-GM.

Key Words: sow housing, social rank, aggression, well-being

INTRODUCTION

Some producers in the United States are transitioning from individual gestation crates to loose housing systems due to consumer and legislative pressure. Group housing systems, provide gestating sows the opportunity to socially interact and exercise per se, but leads to an increase in aggression among the group. Within a group-pen housing system, the highest level of aggression among sows occurs during mixing and around resources (e.g., water, feeding) in order to establish social hierarchy. Aggression among group-housed sows is inevitable during formation of a social hierarchy and reduces overall aggression later on but results in sow performance and productivity to be affected, especially by individual rank.

Previous studies have attempted to improve sow well-being in group housing by equipping pens with feeding stalls, Andersen et al. (1999) found decreased aggression and displacements at trough in pens with feeding stalls. Feeding high fiber gestation diets to sows have been shown to improve satiety, decrease aggression, and reduce stereotypic behaviors (Brouns et al., 1994; Danielsen and Vestergaard, 2001; de Leeuw et al., 2004; de Leeuw et al., 2005). Management strategies may be the key to maintain or improve well-being of submissive sows housed in small group pens by minimizing aggression. We hypothesized that feeding a high-fiber diet to group-penned gestating sows using feeding stalls will minimize aggressive encounters during feeding and improve sow satiety, ultimately improve well-being of the submissive sow. The objective of this study was to assess the impact of keeping gestating sows in small group-pens (9 sows/pen) with different lengths of feeding stalls (LONG or SHORT) and feeding modified high fiber diets (MIDDS-HULLS or DDGS-GM) on the well-being of submissive sows using multiple welfare metrics.

MATERIALS AND METHODS

Animals, Housing and Experimental Design

The University of Illinois Institutional Animal Care and Use Committee approved the protocol for this experiment. Primiparous (first-pregnancy gilts; *n*=39) and multiparous sows (parities 2 to ≥ 6; *n* = 104) derived from Genetiporc Fertilis 25 genetic lines were kept at the University of Illinois Swine Research Center between September 2013 and June 2015 (36/block). Once pregnancy was confirmed, groups of 9 sows were randomly allocated in a 2 x 2 factorial arrangement to group pens fitted with either a 0.6 m (**SHORT**) or 1.8 m (**LONG**) feeding stall and fed a modified gestation diet of either 30% wheat middlings-15% soy hulls (**MIDDS-HULLS**) or 30% DDGS-30% corn germ meal (**DDGS-GM**). Dietary treatments were initiated 2-d (d 35 post-breeding) prior to moving the group into treatment pens. All diets were formulated to meet or exceed NRC requirements (NRC, 2012). Sows were fed 2.23 kg/d MIDDS-HULLS diet from gestational d 35 to 90, and then from d 91 to 104 sows were fed 3.57 kg/d of the diet, while sows fed DDGS-GM diet were fed 2.10 kg/d from d 35 to 90 and 3.37 kg/d from d 91 to 104, respectively. All sows received 6,700 kcal ME/d from gestational d 35 to 90 and 10,720 kcal ME/d from d 91 to 104. Sows were moved to treatment group pens at gestational d 37 and housed in pens at a floor-space allowance 1.7 m^2 /sow (18 ft^2/sow). Feed was added to each feeding stall space within the group pen at 0630 h daily. Each feeding stall space was equipped with an individual nipple waterer and sows had ad libitum access to water.

All newly bred sows were kept in individual crates prior to the start of the study. Sows were AI within 24 h after the onset of estrus and then again 24 h later. Pregnancy was confirmed at d 27 post breeding using an EZ Preg Checker VSS700 (Veterinary Sales and Service Inc., Stuart FL.). On d 37, sows confirmed pregnant were moved to their assigned treatments and

remained in their assigned treatment pens until approximately gestational d 104, when they were moved to a farrowing facility and remained until the end of lactation (d 131). Only 5 sows were removed from the study due to extreme lesions/injuries. All litters were weaned at 21 d of age ± 2, and sows were returned to the breeding facility. If cross-fostering was necessary, it occurred within same treatments.

Social Status

On gestational d 37 (prior to moving into treatment pens) post-feeding, groups of sows were placed in a non-experimental pen to determine social status using a feed competition test previously described by Parent et al. (2012). The non-experimental pen (4.10 m. x 4.10 m) was equipped with one feeder. The feed competition test was captured using EverFocus EQ120/AEN colored camera that was located above the pen and recorded using Geovision GVd1240 for 30 minutes. Initially, sows are acclimated to the non-experimental pen for 5-min, and then 4 kg of the assigned treatment diet was added to the feeder. All aggressive interactions were registered and both the initiator and the receiver during the aggressive encounters were identified. Behaviors registered during feeding competition test included fight, bite, push, chase, and displacement from feeder (Table 2.2). A Dominance Value (DV) was calculated for each sow based on all aggressive interactions that occurred during the feeding competition test. The equation was:

$$DV = \frac{Aggressive\ Encounters\ Initiated}{(Aggressive\ Encounters\ Initiated + Encounters\ Received)}$$

Based on the calculated DV and number of displacements that occurred in experimental pens, 2 sows per group were identified as dominant (**DOM**) and 2 sows were identified as submissive

(**SUB**). This subsample of sows was analyzed separately and used for this analysis (*n*=64; primiparous *n*=21, multiparous *n*=43). After the feed competition, all sows were simultaneously moved to their assigned experimental pen.

Behavior

Sow behavior was captured using EverFocus EQ120/AEN colored cameras (EverFocus Co., LTD., Duarte, CA), Geovision GV-1240 (Geovision, Inc., Irvine, CA) video capture combo card, and viewed using EZViewLog (Geovision, Inc., Irvine, CA), cameras were fixed above each pen to view the entire area and lights were kept on 24 h a day. The Geovision combo card was programmed to record for the first 48 h after mixing and then again for 24 h on a bi-weekly basis. Live behavioral observations were registered during feeding at various time points including first feeding post-mixing, and then every 3-wk thereafter until sows were moved to farrowing facility to analyze aggressive behaviors that occur during feeding. Frequencies and durations of every aggressive encounter (AE) during these time periods was registered which included push, bite, fight, and threat, and for each encounter the initiating and receiving sow was registered (Table 2.2). At collection of blood glucose samples, posture and behavior for each sow was recorded to analyze possible correlations. Behaviors registered were eat, drink, sham chew, oral-nasal-facial (ONF), locomotion, stand, sit, and lay at blood glucose collection (Table 2.2).

Blood Sample Collection and Analysis

Blood samples were collected on gestational d 30, 70, 90, 104, and again at the end of lactation (~ 15 mL) ± 1 d via jugular venipuncture using 30 mL syringes containing 2 mL heparin. Sows were snared and blood samples were obtained > 2 mins. Whole blood smears were

made, fixed in methanol, stained with Hema-3 staining system (Fisher Scientific, Houston, TX) and leukocyte differential counts were determined under a light microscope. Total white blood cell counts (WBC) were determined using a Coulter Z1 particle counter (Beckman Coulter, Miami, FL) by adding 10 µL of whole blood to 10 mL of Isoflow (Beckman Coulter) and 3 drops of Zap-oglobin (Beckman Coulter) to lyse red blood cells.

For functional immune assays, 12 mL of whole blood was carefully layered over Histopaque 1077 (density = 1.077 g/mL; Sigma Aldrich, Saint Louis, MO) and 1119 (density = 1.119 g/mL; Sigma Aldrich) and centrifuged for 30 minutes at 700 x g and 25° C. Mixed lymphocyte population was aspirated from the 1077 layer and neutrophils from the 1119 layer. The lymphocyte layer was washed with Roswell Park Memorial Institute media (RPMI; Gibco, Carlsbad, CA), centrifuged for 15 minutes at 1160 x g and 4° C, the pellet was then dissolved in RPMI/5% Fetal Bovine Serum (FBS) and incubated (37°C in a 5% CO_2 humidified incubator) in a petri dish for 1 h to isolate lymphocytes. After 1 h of incubation, non-adherent cells were washed in RPMI, resuspended in RPMI and counted (Beckman Coulter). Neutrophils were washed three times in RPMI, resuspended in Phosphate Buffered Saline (PBS; Fisher Scientific, Houston, TX) and counted (Beckman Coulter). Cell concentrations were adjusted for the specific requirements of each immune assay. Plasma was collected and stored at -20° C until further analysis.

Immune Assays

To assess innate immune status of sows, natural killer cell (NK) cytotoxicity and neutrophil chemotaxis were measured. Neutrophil chemotaxis was measured using an assay previously described by Salak et al. (1993) and Sutherland et al. (2005). Briefly, neutrophils

were used at a concentration of 3 x 10^6 cells/mL, assay medium (RPMI) as a control and recombinant human complement-5a (10^{-5} M; Sigma Aldrich) was used as a chemoattractant. NK cell cytotoxicity was measured using a commercially available nonradioactive cytotoxicity detection kit (Roche Diagnostics, Indianapolis, IN), following the manufacture's protocol and as described by Sutherland et al. (2005) with modifications. Briefly, lymphocytes were used as effector cells and K-562 chronic human myelogenous leukemia cells (American Tissue Type Culture Collection, Manassas, VA) were used as target cells. Lymphocytes were adjusted to concentration of 1 x 10^7 cells/mL, K-562 cells were adjusted to a constant 10,000 cells/well, samples were run in triplicate at effector (lymphocytes) to target cell (K-562) ratios of 12.5:1, 25:1, 50:1, and 100:1. Plates were read using a microplate reader (Thermo Scientific Instruments, Waltham, MA) at a wavelength of 490 nm and reference wavelength of 690 nm. Percent cytotoxicity was calculated as described by Lumpkin and McGlone (1992), and an assay was considered valid if maximum release divided by spontaneous release was ≤ 30%.

To assess adaptive immune status of sows, mitogen induced lymphocyte proliferation assay was performed. Briefly, in triplicate, 100 µL of lymphocytes at a concentration of 5 x 10^6 cells/mL were added to a 96-well flat bottom plate. Concanavalin A (ConA; Sigma Aldrich) and lipopolysaccharide (LPS; Sigma Aldrich) were used as mitogens (ConA: 0, 2, and 20 µg/mL; LPS: 0, 5, and 50 µg/mL) to stimulate T and B cells, respectively. Plates were incubated for 48 h at 37°C in a 5% CO_2 humidified incubator, then 100 µL from each well was removed and 100 µL of RPMI/10% FBS was added, plates were then incubated for 18 h. After 18 h incubation 20 µL of 3-[4, 5-dimethylthiazol-2-yl]-2, 5-diphenyltetrazolium bromide (MTT; Sigma Aldrich) was added to each well, and the plates were incubated for 4 h. Acidified isopropanol (100 µL of 0.1 N HCL in anhydrous isopropanol) was added to each well and plates were read within an hour

using a microplate reader (Thermo Scientific Instruments) at a wavelength of 600 nm. The results are expressed as a proliferation index: Optical density of stimulated cells ÷ Optical density of nonstimulated cells.

Plasma Analysis

Total plasma cortisol was measured on d 30 (baseline) and d 90 of gestation using a commercially available RIA cortisol kit, following the manufacturer's protocol with exception of standards made in stripped porcine plasma (MP Biomedicals, Santa Ana, CA). Briefly, in duplicate, 25 μL of sample or standard were added to antibody-coated tubes. 1 mL of radiolabeled (I^{125}) cortisol was added to tubes, vortex, and incubated for 45 min in water bath at 37°C. The liquid phase was aspirated and radioactivity was counted with a gamma counter. A standard curve based on 0, 8, 16, 32, 62.5, 125, and 250 ng/μL was used. Intra- and interassay CV were 9.1% and 8.3% respectively, and sensitivity of 3 pg. Plasma IL-12 was measured on d 30 (baseline) and d 90 of gestation using a commercially available ELISA nonradioactive kit, following the manufacturer's protocol (R&D Systems, Minneapolis, MN). Briefly, in duplicates, 100 μL of diluted sample or standard and 50 μL of assay diluent was added to 96-well microplate coated with a monoclonal antibody specific for porcine IL-12/IL-23 p40. Plates were incubated for 2 h at room temperature on a horizontal orbital microplate shaker and then each well was aspirated and washed five times with wash buffer. Conjugate solution (200 μL) was added to each well and incubated for another 2 h on the shaker. Each well was aspirated and washed five times, then 120 μL of substrate solution was added to each well and incubated for 30 min on the benchtop protected from light. After 30-min incubation, the reaction was stopped with 120 μL of stop solution to each well, and plates were read using a microplate reader (Thermo Scientific

Instruments) at a wavelength 450 nm. A standard curve based on 0, 47, 94, 188, 375, 750, 1500, and 3000 pg/mL was used.

Blood Glucose Collection

Blood glucose levels were measured 2 d prior to and after treatment diets were fed, then every 3 d for the first two weeks post-mixing, and then again on a biweekly basis until sows were moved into farrowing crates. Blood glucose was measured 30 min prior to feeding and 30, 60, 90, and 120 min post feeding at each measurement day. The Precision Xtra monitor was used in combination with Precision Xtra strips (Abbott, Alameda, CA) to immediately determine the glucose level in a drop of blood as previously described by de Leeuw et al. (2005). A drop of blood was obtained from the ear vein using a small needle (20 gauge, 1 in.; Excel International). Samples that were not obtained within 5 min were excluded from the analysis.

Performance and Productivity Traits and Lesions Scores

Sow BW was taken on gestational d 30, 70, 90, 104, and end of lactation (~ d 131), ± 1 d. Sow backfat depth (BF) and body condition score (BCS) were taken on gestational d 30, 90, 104 and end of lactation ± 1 d. Sow BF depth was measured using a longitudinal imaging ultrasound scan cranial to the last rib using an Aloka-500V ultrasound machine (Hitachi Aloka, Walllingford, CT). Sow BCS was determined using visual-appraisal (sow's rear aspect) method (1= emancipated to 5= obese) described by Coffey et al. (1999) and DeDecker et al. (2014). Body lesions scores were taken prior to moving into treatment pen (day 0), 1 d after mixing, and every 3 d for the first two weeks post-mixing (phase 1), and then on bi-weekly basis until gestational d 104, and again at the end of lactation (phase 2). Body lesion scores included hair

coat condition, dung freedom, lameness, and various body regions. Body regions (Fig. 2.1) used to assess lesion scores included the head, ears, neck, chest/breast, shoulders, back, udder, rear, vulva, legs and hooves. Lesion scores were based on the presence or absence of an apparently new or old lesion in conjunction with severity of the wound (0 = normal/no lesions; 1 = dehairing, callus, balding; 2 = redness, swelling; 3 = swelling plus callus, abscess; 4 = moderate wound, scabbed over scratch; 5 = marked wound, fresh scratch; 6 = severe wound, open wound; and 7 = severe swelling). Averaging all scores from each body location for each sow resulted in a total body lesion severity score. Litter-related traits included total number of piglets born and born alive, and numbers of females, males, stillborn, mummified, laid on, euthanized, and total mortality (no. stillborn + no. mummified + no. laid on + no. euthanized), and piglets weaned. Calculated litter traits included litter BW at birth, adjusted litter BW at birth (adjusted by number of piglets born), litter wean BW, adjusted litter wean BW (adjusted by number of piglets weaned), and mean piglet weaning BW.

Statistical Analysis

Post hoc analysis was conducted on social status classification. All data were analyzed with the mixed models procedure of SAS (SAS Inst. Inc., Cary, NC), with repeated measures. All traits were tested for departures from normal distribution, and transformations were applied to traits deviating from normal distribution. A linear mixed-effects model was used to analyze measurements, the model included all possible 2- and 3-way interactions of the fixed effects of diet (MIDDS-HULLS or DDGS-GM), feeding stall length (LONG or SHORT), and sow social status (DOM or SUB). A random effect of replicate was included in the model to account for potential environmental and management differences across groups. The model for physiological

measures also included day of measurement (levels varies depending on measurement). The model for behaviors observed during feeding and blood glucose also included day post treatment (dietary or stall length treatment), which varied depending on measurement. Lesion scores being an ordinal variable required analysis with PROC GLIMMIX (SAS Inst. Inc., Cary, NC) to determine the means with a response distribution of Gaussian. Least square means were generated and separated statistically with pairwise *t* tests (PDIFF option). Significance was set at $P \leq 0.05$, whereas trends were discussed at $P \leq 0.10$.

RESULTS and DISCUSSION

Aggression among group-housed gestating sows can lead to an increase in lesion scores, injuries and reduced productivity (Li and Gonyou, 2013; Knox et al., 2014). Most aggression occurs upon mixing and at feeding, especially around resources (e.g. feed and water). At mixing, sows engage in aggressive encounters to establish a social hierarchy, but once social stability is achieved sows tend to engage in conflicts around resources. If a competitive feeding system is used in a group-housing system, this increases the opportunity for the more-dominant sows within the group to displace submissive sows from their feeding space before they have time to consume their daily allotment of feed. Variability in feed consumption among the group leads to variation in body conditions scores. Social status and feeding systems are important factors that need to be considered when managing sows in group-pens, especially for submissive sows. Therefore, we hypothesized that sows fed a high-fiber diet in conjunction with feeding stalls in a group-pen housing environment would decrease aggressive encounters during feeding and improve sow satiety, which may improve the well-being of submissive sows. The results of the present study validate the effects of feeding stalls and feeding a high-fiber diet on multiple welfare measures for submissive sows.

Performance, Lesion Scores, and Productivity

Presented in Table 2.3 are interactive effects of social status × feeding stall length and social status × diet for performance traits of gestating sows. An interactive effect occurred for sow BW at gestational d 30 ($P < 0.002$), and a tendency on gestational d 70 and 90 ($P < 0.10$), and total BW gain ($P < 0.08$). Socially, SUB sows kept in pens with LONG feeding stalls had greater BW and BW gain compared with SUB sows kept in pens with SHORT feeding stalls. DOM sows were heaviest and gained most BW from gestational d 30 to 70 when kept in pens with SHORT feeding stalls (social status × stall length; $P < 0.02$), and SUB sows had less BW and BW gain than did DOM sows.

Social status × diet interaction occurred for mean BW ($P < 0.01$), BW gain ($P < 0.04$) and total gain ($P < 0.02$) at all gestational days. Socially, DOM sows had the greatest BW gain when fed DDGS-GM diet, but BW gain was similar when fed MIDDS-HULLS diet. The SUB sows had greatest BW gain when fed MIDDS-HULLS diet and performed equally as DOM sows ($P < 0.02$; Figure 2.2). Socially, DOM sows tended to have greater BF depth when fed DDGS-GM diet and SUB sows had similar BF regardless of diet (social status × diet; $P < 0.06$). There were no interactive effect of social status × feeding stall length ($P < 0.43$) or social status × diet ($P < 0.18$) for sow BCS. Previous studies have shown socially dominant sows gained more BW than socially submissive sows (O'Connell et al., 2003; Zhao et al., 2013); however, in this study when submissive sows were fed MIDDS-HULLS diet they had similar BW gain as dominant sows and even greater BW when housed in pens with LONG feeding stalls. This suggests the submissive sows may have benefited from feeding stalls, specifically longer feeding stalls than short, and a high fiber diet with MIDDS-HULLS to provide protection and/or energy from aggressive encounters throughout gestation.

Presented in Table 2.4 are the interactive effects of social status × feeding stall length and social status × diet on body lesion severity scores. Both, DOM and SUB sows had the highest total lesions when housed in pens with LONG feeding stalls than in pens with SHORT feeding stalls ($P < 0.03$; Fig. 2.3). Social status × diet interactions occurred for skin lesion scores at head ($P < 0.002$), ears ($P < 0.08$), side ($P < 0.002$), back ($P < 0.07$), and vulva ($P < 0.06$). Total severity scores were lowest ($P < 0.003$) for sows housed in pens with SHORT feeding stalls and fed DDGS-GM diet, regardless of social status (social status × diet × stall length; Fig. 2.4). An interaction effect of social status × feeding stall length occurred for productivity traits, specifically average piglet wean BW ($P < 0.05$), and adjusted litter BW ($P < 0.06$) and litter wean BW ($P < 0.07$) (Appendix A.3). Socially, SUB sows housed in pens with LONG feeding stalls had the heaviest ($P < 0.05$) piglet wean BW and similar piglet weaned BW as DOM sows (Fig. 2.5). Piglets weaned from socially, SUB sows housed in pens with LONG feeding stalls and fed DDGS-GM diet had the heaviest adjusted litter ($P < 0.01$; Fig. 2.6) and piglet wean BW ($P < 0.005$; Fig. 2.7) (social status × diet × stall length; Appendix A.4). Productivity measures were similar regardless of social status and dietary treatment (social status × diet; $P > 0.01$; Appendix A.3).

In the present study lesion scores were the highest when sows were housed in pens with LONG feeding stalls, regardless of social status, however sow BW gain and piglet wean BW were highest for sows in pens with LONG feeding stalls. This indicates the high lesion scores may have been a result of the experimental design of the pens with LONG feeding stalls than a true treatment effect. Productivity results in this study are in agreement with a previous study that showed socially dominant sows had lower litter BW than socially submissive sows (Zhao et al., 2013), however others have found no effect of social status on productivity (Arey, 1999;

Chapinal et al., 2010). Arey (1999) and Chapinel et al. (2010) determined social status by observing aggressive behaviors, while Zhao et al. (2013) and our present study used aggressive behaviors observed in a dominant value or winning percentage formula to determine social status, this may have influenced their results.

Immune and Behavior

Socially, SUB sows housed in pens with LONG feeding stalls had greater ($P < 0.04$) neutrophil counts and blood glucose levels (Fig. 2.8) than sows in other treatment combinations (social status × stall length). An interaction effect of social status × feeding stall length also occurred for total WBC, percentage of lymphocytes, monocytes, and immature (banded) neutrophils ($P < 0.10$; Table 2.5). Socially, DOM sows had the lowest ($P < 0.07$) glucose level and percentage of monocytes ($P < 0.03$) when fed DDGS-GM diet, and SUB sows had similar levels regardless of diet, but greater similarity to DOM sows that were fed MIDDS-HULLS (social status x diet; Appendix A.5). Percentage of lymphocytes ($P < 0.08$), cortisol concentration ($P < 0.08$), and neutrophil:lymphocyte ratio (N:L; $P < 0.04$) were all affected by social status × diet × stall length interaction (Appendix A.6). The N:L ratio was greatest for DOM sows housed in pens with SHORT feeding stalls and fed MIDDS-HULLS diet, and SUB sows housed in pens with LONG feeding stalls and fed the same diet had the lowest ratio. It is plausible that submissive sows differentially divert energy toward other biological resources than did dominant sows, suggesting social status and its individual perceived threat level may affect the biological response of sows in group housing systems.

Total aggressive encounters (AE; $P < 0.02$) and no. of AE towards SUB sows were lowest ($P < 0.004$) when housed in pens with LONG feeding stalls and fed DDGS-GM while the lowest AE:Displacement ratio ($P < 0.01$) occurred among those sows housed in pens with

SHORT feeding stalls regardless of diet (diet × stall length; Table 2.6). Total AE ($P < 0.003$), AE:Displacement ($P < 0.04$), no. AE towards SUB sows ($P < 0.001$), and percentage of SUB sow displaced (Fig. 2.9) continuously decreased when housed in pens with LONG feeding stalls during gestation than in pens with SHORT feeding stalls (feeding stall length × day post stall treatment; Table 2.7). An interaction effect of feeding stall length × day post stall treatment also occurred for no. AE by DOM sows ($P < 0.004$), no. displacements by DOM sows ($P < 0.03$), no. AE by DOM towards SUB sows ($P < 0.002$), and no. displacements by DOM sows towards SUB sows ($P < 0.09$). Presented in Table 2.8 is interactive effects of social status × stall length and social status × diet on behaviors registered during hours of glucose collection. Socially, SUB sows spent greater ($P < 0.05$) percentage of time lying when housed in pens with SHORT feeding stalls, whereas, sows housed in pens with LONG feeding stalls, regardless of social status spent greatest ($P < 0.02$) percentage eating. Percentages of stand ($P < 0.02$) and sit ($P < 0.0001$) behaviors were greatest for SUB sows fed DDGS-GM and SUB sows fed MIDDS-HULLS diet spent the most time eating ($P < 0.004$; Table 2.8). Presented in Table 2.9 is interactive effect of social status × diet × feeding stall length on behaviors registered during hours of glucose collection. Percentages of stand ($P < 0.006$) and lay ($P < 0.003$) were greatest for SUB sows housed in pens with SHORT feeding stalls and fed DDGS-GM diet compared to sows in other combinations. When housed in pens with SHORT feeding stalls and fed DDGS-GM diet, SUB sows expressed lowest ($P < 0.0001$) percentage of ONF behavior. Social status × time post feed delivery interactive effect occurred for percentages of stand ($P < 0.0001$), sit ($P < 0.10$), ONF ($P < 0.002$), and sham chewing ($P < 0.005$; Table 2.10). SUB sows displayed lower percentage of stereotypies (ONF and sham chewing) than did DOM sows post feeding (Fig. 2.10). Submissive sows receive more aggression and were displaced more often from the feeder

(Andersen et al., 1999; O'Connell et al., 2003). Consequently in this study, submissive sows in group pens with feeding stalls and fed a high fiber diet experienced the least number of aggressive encounters, expressed greater percentage of satiety behaviors (stand, sit, lay) and lower percentage of stereotypies. Submissive sows fed DDGS-GM diet may have had more energy stores as they avoided conflicts during gestation than did dominant sows, as they were the aggressors and more than likely had to expand energy during aggressive interactions and maintaining social status.

Feeding systems are shown to have different effects on sows by individual social rank. Previous studies report submissive sows benefit from simultaneous and protective feeders against other sows in group housing (Andersen et al., 1999; O'Connell et al., 2003). These findings indicate that sows were able to adapt to their housing environment and social stress, regardless of social status, as all of the sows had similar number of piglets born and born alive and weaned the same number of piglets. Nonetheless, this study confirms the influence of feeding system by social rank, specifically submissive sows seemed to benefit most when housed in pens with LONG feeding stalls and fed DDGS-GM diet. They experienced the least number of aggressive encounters and had heavier litter weaning BW and average piglet wean BW when compared with submissive sows in other treatment combinations, which may have improved their well-being.

Implications

Housing gestating sows in group pens with long feeding stalls and feeding them a high fiber diet with DDGS-corn germ meal may improve the well-being of socially submissive sows. Thus, combining feeding stalls and dietary management strategies can impact sow well-being

based on social rank and future housing systems should consider social status when implementing a competitive feeding system.

An issue that arose in the study was the loss of a small number (5 out of 144) of sows that were unable to adapt to the feeding system. Sows were given a few days to adjust to the feeding system and floor fed if necessary, but if sows did not adjust they were removed from pen and placed in gestation crates. A second issue that arose in the study was the amount of dung/pen space for sows housed in pens with LONG feeding stalls. Although both treatment pens had equal floor space per sow, the dung/pen area in treatment with LONG feeding stall was too small for the larger sows to turnaround. A succeeding study would increase the dung/pen area for pens with LONG feeding stalls.

LITERATURE CITED

Andersen, I. L., K. E. Bøe, and A. L. Kristiansen. 1999. The influence of different feeding arrangements and food type on competition at feeding in pregnant sows. Applied Animal Behaviour Science 65: 91-104.

Arey, D. S. 1999. Time course for the formation and disruption of social organisation in group-housed sows. Applied Animal Behaviour Science 62: 199-207.

Brouns, F., S. A. Edwards, and P. R. English. 1994. Effect of dietary fibre and feeding system on activity and oral behaviour of group housed gilts. Applied Animal Behaviour Science 39: 215-223.

Chapinal, N. et al. 2010. Aggressive Behavior in Two Different Group-Housing Systems for Pregnant Sows. Journal of Applied Animal Welfare Science 13: 137-153.

Coffey, R. D., G. Parker, and K. Laurent. 1999. Assessing sow body condition. ASC-158 Publication on-line at http://www. thepigsite. com/FeaturedArticle/Default. asp.

Danielsen, V., and E.-M. Vestergaard. 2001. Dietary fibre for pregnant sows: effect on performance and behaviour. Animal Feed Science and Technology 90: 71-80.

de Leeuw, J. A., A. W. Jongbloed, and M. W. A. Verstegen. 2004. Dietary Fiber Stabilizes Blood Glucose and Insulin Levels and Reduces Physical Activity in Sows (Sus scrofa). Journal of Nutrition 134: 1481-1486.

de Leeuw, J. A. et al., 2005. Effects of levels and sources of dietary fermentable non-starch polysaccharides on blood glucose stability and behaviour of group-housed pregnant gilts. Applied Animal Behaviour Science 94: 15-29.

DeDecker, A. E., A. R. Hanson, P. M. Walker, and J. L. Salak-Johnson. 2014. Space allowance and high fiber diet impact performance and behavior of group-kept gestating sows. Journal of Animal Science 92: 1666-1674.

Knox, R., J. Salak-Johnson, M. Hopgood, L. Greiner, and J. Connor. 2014. Effect of day of mixing gestating sows on measures of reproductive performance and animal welfare. Journal of Animal Science 92: 1696-1705.

Li, Y., and H. Gonyou. 2013. Comparison of management options for sows kept in pens with electronic feeding stations. Canadian Journal of Animal Science 93: 445-452.

Lumpkin, E. A., and J. J. McGlone. 1992. A 51Cr Release Assay for the Determination of Natural Killer Cell Cytotoxicity. Journal of Nutritional Immunology 1: 63-74.

NRC. 2012. Nutrient Requirements of Swine: Eleventh Revised Edition, Washington, DC.

O'Connell, N. E., V. E. Beattie, and B. W. Moss. 2003. Influence of social status on the welfare of sows in static and dynamic groups. Animal Welfare 12: 239-249.

Parent, J.-P., M.-C. Meunier-Salaün, E. Vasseur, and R. Bergeron. 2012. Stability of social hierarchy in growing female pigs and pregnant sows. Applied Animal Behaviour Science 142: 1-10.

Salak, J. L., J. J. McGlone, and M. Lyte. 1993. Effects of in vitro adrenocorticotrophic hormone, cortisol and human recombinant interleukin-2 on porcine neutrophil migration and luminol-dependent chemiluminescence. Veterinary Immunology and Immunopathology 39: 327-337.

Sutherland, M. A., S. L. Rodriguez-Zas, M. Ellis, and J. L. Salak-Johnson. 2005. Breed and age affect baseline immune traits, cortisol, and performance in growing pigs. Journal of Animal Science 83: 2087-2095.

Zhao, Y., W. L. Flowers, A. Saraiva, K. J. Yeum, and S. W. Kim. 2013. Effect of social ranks and gestation housing systems on oxidative stress status, reproductive performance, and immune status of sows. Journal of Animal Science 91: 5848-5858.

TABLES and FIGURES

Table 2.1 Composition of experimental diets fed to gestating sows

Item	MIDDS-HULLS	DDGS-GM
Ingredients, %		
Corn	38.9	33.65
Soybean meal, 48%	12.5	2.5
Soybean hulls	15	-
Wheat middlings	30	-
DDGS	-	30
Corn germ meal	-	30
Soybean oil	1	1
Limestone	1.3	1.6
Dicalcium phosphate	0.6	0.55
Salt	0.4	0.4
Vitamin mineral premix	0.3	0.3
Total	100	100
Energy and nutrients		
Energy, Kcal ME/kg	2,999	3,177
Crude protein, %	13.78	18.96
Calcium, %	0.78	0.78
Phosphorus, %	0.61	0.66
Phosphorus, digestible, %	0.34	0.34
Acid detergent fiber, %	9.81	7.93
Neutral detergent fiber, %	23.97	25.75
Amino Acids[1]		
Arginine, %	0.9	0.83
Histidine, %	0.35	0.52
Isoleucine, %	0.59	0.49
Leucine, %	1.05	1.34
Lysine, %	0.61	0.61
Methionine, %	0.21	0.45
Methionine + cysteine, %	0.46	0.66
Phenylalanine, %	0.6	0.58
Threonine, %	0.43	0.51
Tryptophan, %	0.15	0.23
Valine, %	0.59	0.59

Table 2.2 Definitions of observed and registered behaviors

Behavior	Description
Aggressive Behaviors	
Bite	Opening and closing mouth near or on any part of another sow
Chase	Pursuit with the intent of further aggression to another sow
Push	Hitting another sow with head or snout
Fight	Vigorous reciprocated aggression (repeated biting and pushing)
Displacement	Physically and aggressively removing another sow from feeder, feeding stall, or pen area
Threat	Aggressive act but does not make any physical contact
Lay	Reclining in lateral or ventral position, no other behavior occurring
Sit	Supported by two front legs, no other behavior occurring
Stand	Supported by all four legs and no other behavior occurring
Locomotion	Sow is moving by supporting weight on one diagonal pair at a time
Eat	Snout/mouth in contact with feed or head is over or in the feeder when food is present
Drink	Snout/mouth in contact with the water nipple
Sham-chewing	Mouth empty while moving jaw in a repetitive chewing motion
Oral-nasal-facial	Snout or mouth in contact with any object besides food or water

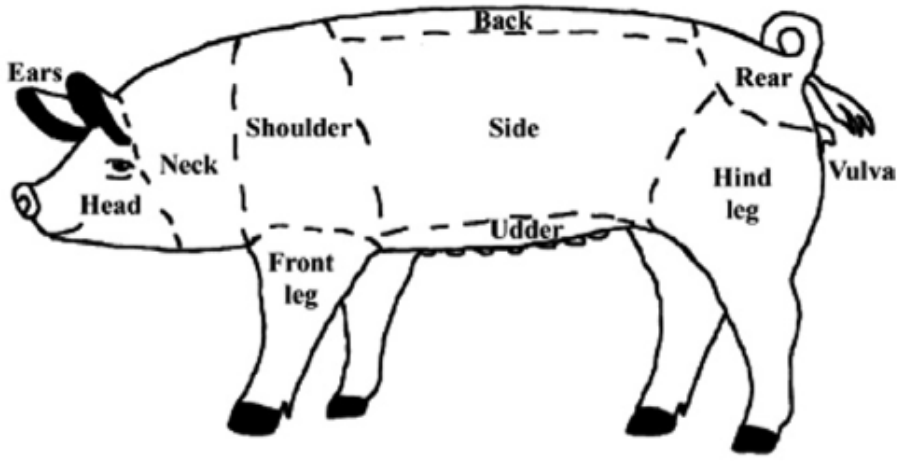

Figure 2.1 Schematic of body regions used to assess body lesion scores

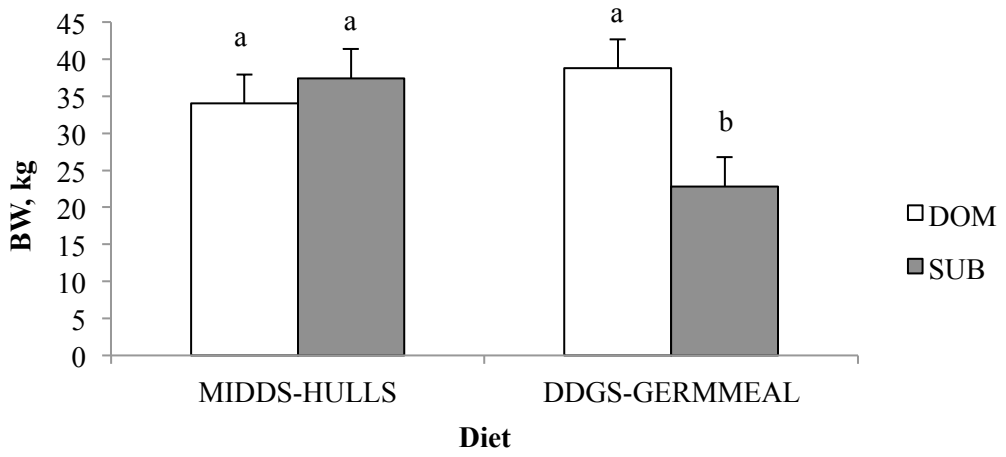

Figure 2.2 Social status × dietary treatment interaction on total BW gain ($P = 0.02$)

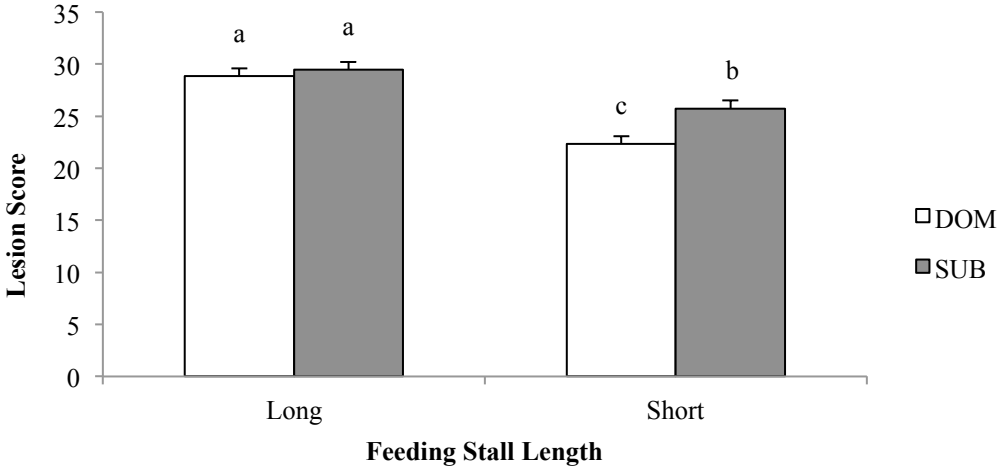

Figure 2.3 Social status × feeding stall length on total lesion score ($P = 0.03$)

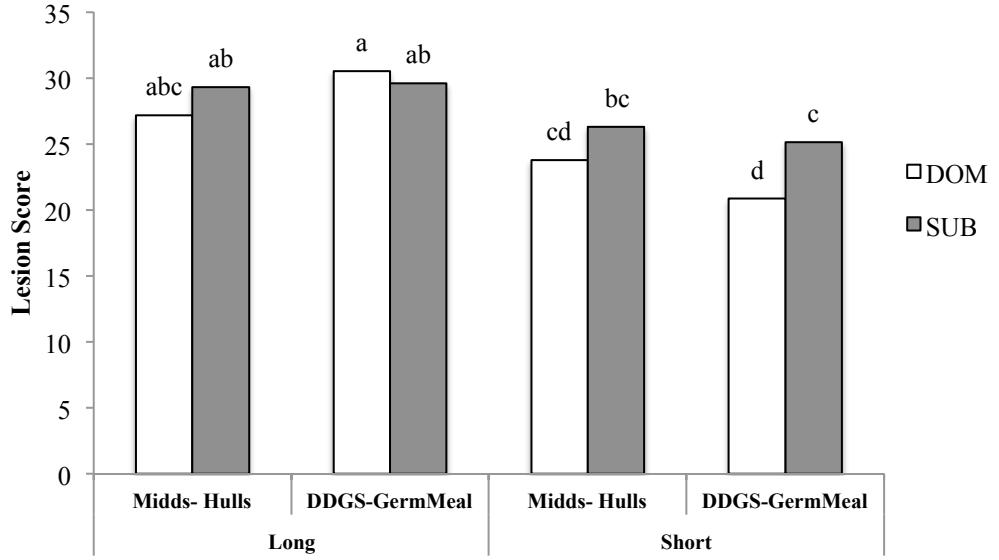

Figure 2.4 Social status × diet × feeding stall length effect on total mean severity score (*P*=0.003)

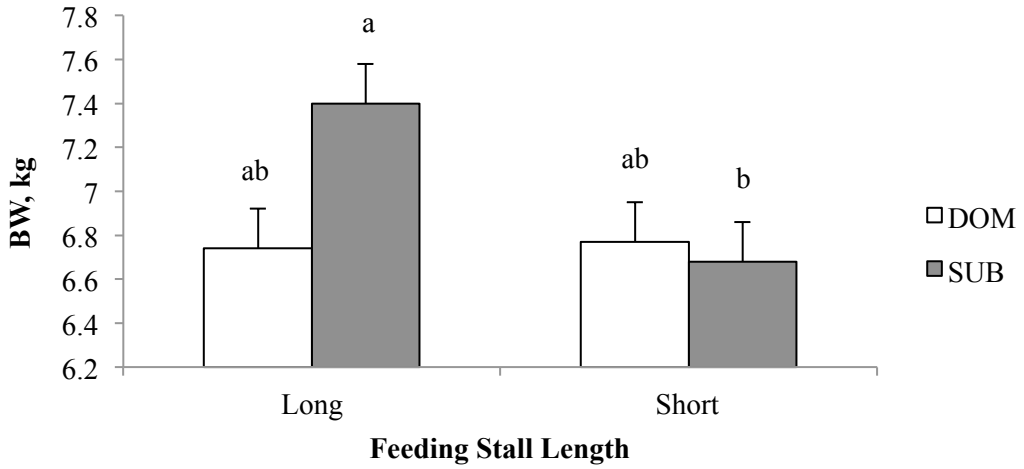

Figure 2.5 Social status × feeding stall length on average piglet wean BW (*P=0.05)*

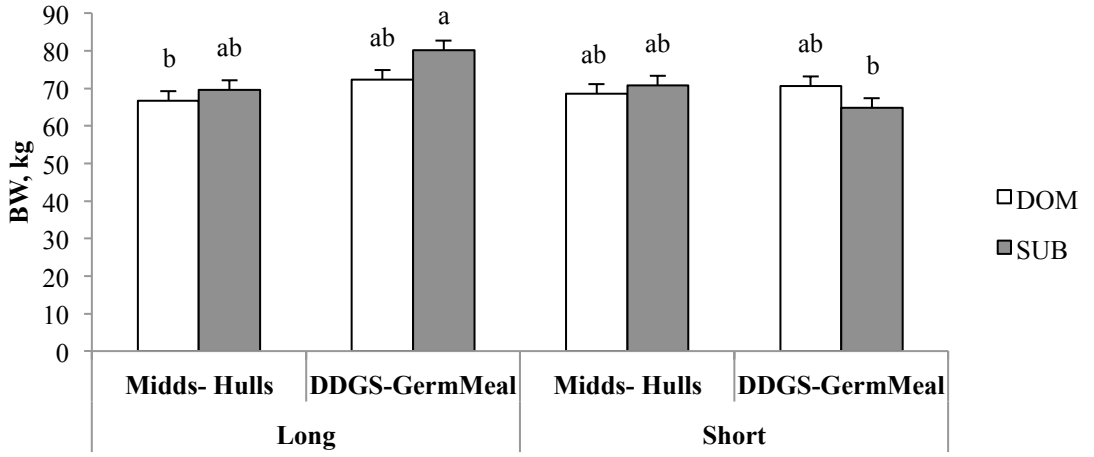

Figure 2.6 Social status × diet × feeding stall length effect on adjusted litter wean BW (*P*=0.01)

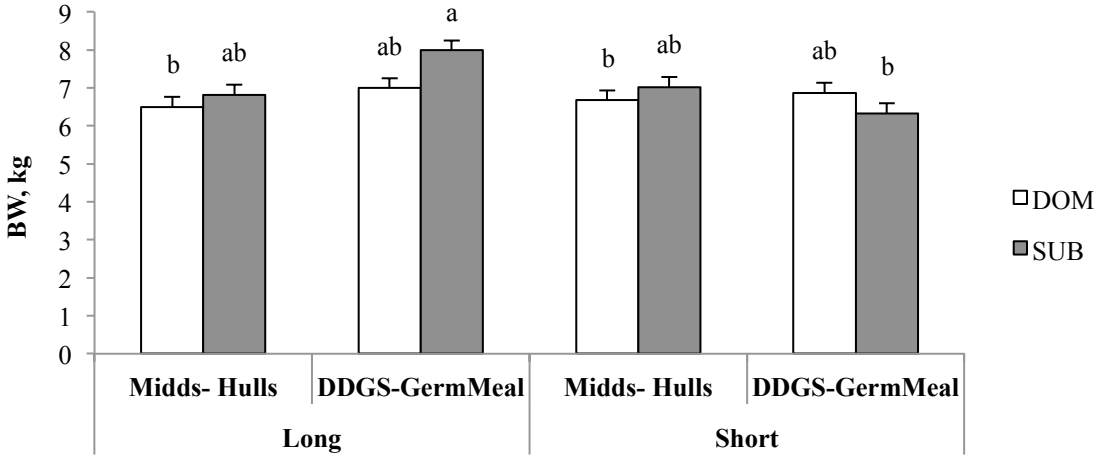

Figure 2.7 Social status × diet × feeding stall length effect on average piglet wean BW (*P*=0.005)

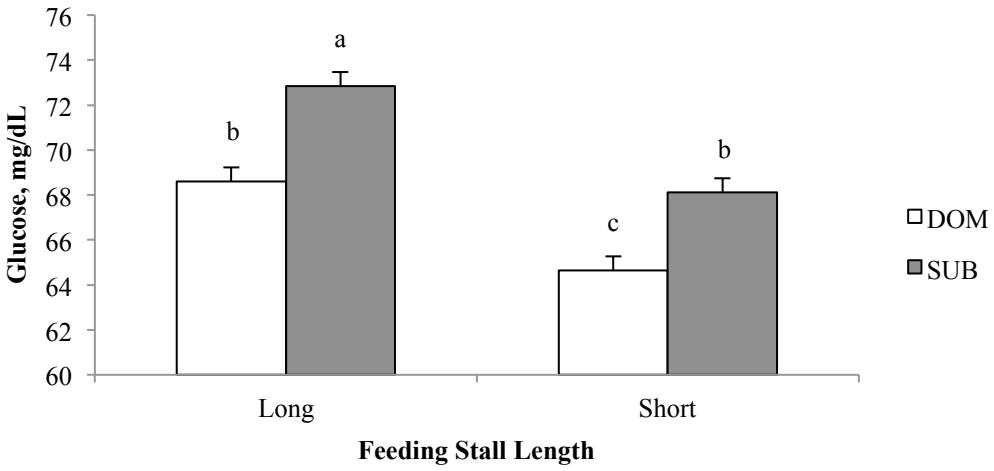

Figure 2.8 Social status × feeding stall length on blood glucose (*P*=0.04)

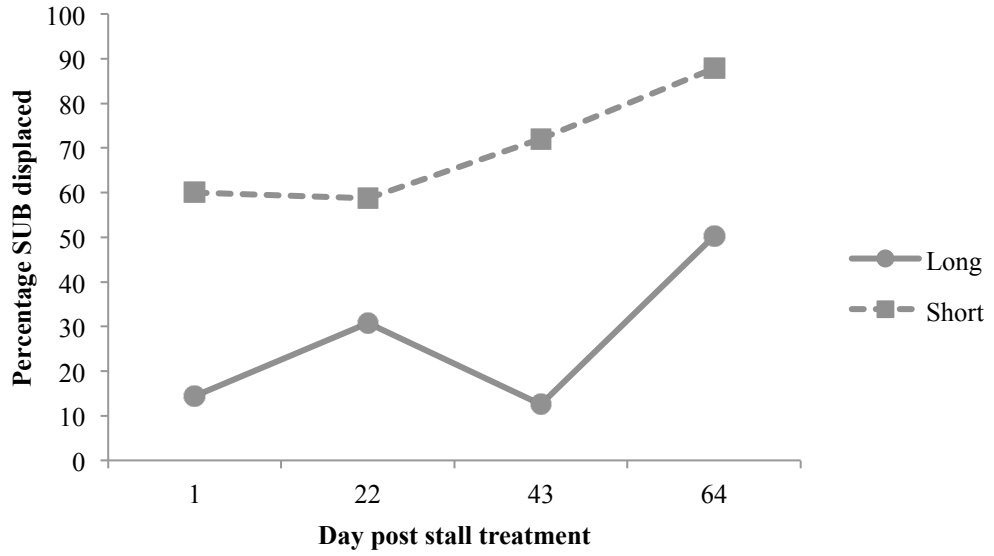

Figure 2.9 Feeding stall length x day post stall treatment effect on percentage of SUB sows displaced by DOM sows

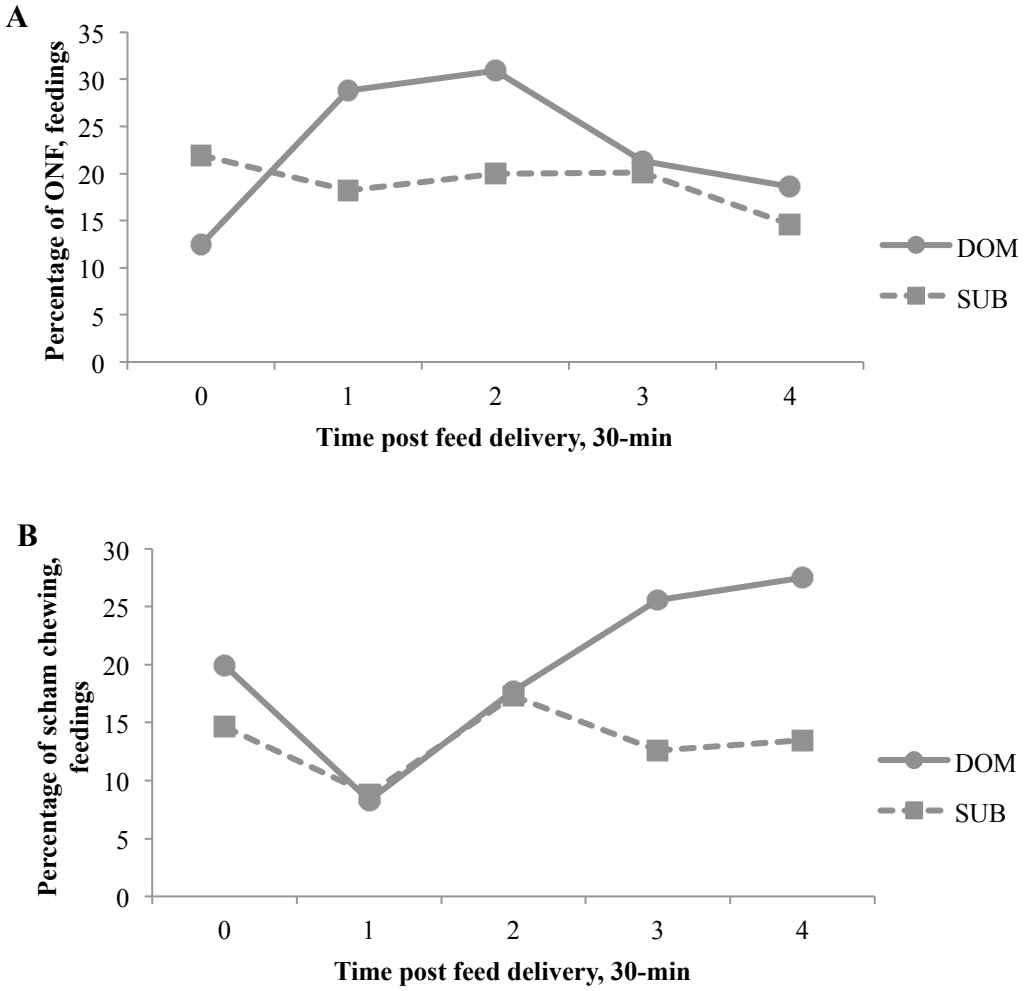

Figure 2.10 Percentage of stereotypic behaviors for social status x time post feed delivery. A) Oral-nasal-facial (ONF; $P < 0.002$). B) Sham chewing ($P < 0.005$).

Table 2.3 Interactive effects of social status x feeding stall length and social status x diet on sow performance (Least Square Means)

	Social Status*Feeding Stall Length						Social Status*Diet					
	DOM		SUB				DOM		SUB			
Item	Long	Short	Long	Short	SE	P-value	Midds-Hulls	DDGS-GM	Midds-Hulls	DDGS-GM	SE	P-value
BW d 30, kg	242.81[a]	223.44[b]	183.44[c]	192.81[c]	4.38	0.002	235.16	231.09	190.31	185.94	4.38	0.97
BW d 70, kg	223.83	227.37	218.49	212.15	3.32	0.10	223.38[a]	227.83[a]	218.74[ab]	211.91[b]	3.29	0.04
BW d 90, kg	226.62	233.46	224.89	219.51	3.95	0.09	227.13[ab]	232.95[a]	227.28[a]	217.11[b]	3.89	0.02
BW d 104, kg	247.09	251.98	241.79	235.76	4.85	0.22	247.39[a]	251.68[a]	246.27[a]	231.28[b]	4.78	0.02
BW d 135, kg	217.04	224.76	215.59	212.03	4.36	0.15	216.21	225.59	215.21	212.41	4.35	0.10
BW Mean, kg	227.37	231.49	224.11	220.22	2.92	0.14	227.43[a]	231.42[a]	226.20[a]	218.13[b]	2.88	0.01
BW Gain 1 (d 30 to 70), kg	10.16[ab]	15.78[a]	11.25[ab]	3.97[b]	2.71	0.02	10.53[ab]	15.41[a]	10.75[ab]	4.47[b]	2.71	0.04
BW Gain 2 (d 70 to 90), kg	2.95	4.29	5.03	4.19	1.31	0.41	3.73	3.51	6.19	3.03	1.31	0.27
BW Gain 3 (d 90 to 104), kg	19.86	18.29	17.44	16.56	1.34	0.80	19.80	18.36	19.37	14.63	1.34	0.22
BW Total Gain, kg	32.91	39.86	33.72	26.50	3.95	0.08	34.00[a]	38.76[a]	37.42[a]	22.81[b]	3.95	0.02
BW Loss, kg	-29.79	-28.95	-26.05	-24.21	3.95	0.90	-32.23	-26.51	-30.13	-20.13	4.11	0.58
BF Mean, cm	1.89	1.88	1.74	1.64	0.04	0.26	1.82	1.95	1.70	1.68	0.04	0.06
BCS, 1-5	3.05	2.99	2.96	2.97	3.60	0.43	3.05	2.98	2.95	2.98	3.60	0.18

[a-c] Means within a row with different superscripts differ ($P \leq 0.05$).

Table 2.4 Interactive effects of social status x feeding stall length and social status x diet on sow body lesion scores (Least Square Means)

	Social Status*Feeding Stall Length						Social Status*Diet					
	DOM		SUB				DOM		SUB			
Item	Long	Short	Long	Short	SE	P-value	Midds-Hulls	DDGS-GM	Midds-Hulls	DDGS-GM	SE	P-value
Total Severity	28.84[a]	22.32[c]	29.46[a]	25.74[b]	0.77	0.03	25.48	25.68	27.82	27.38	0.77	0.62
Head, 0-7	2.10	1.63	1.69	1.53	0.19	0.36	2.10[a]	1.63[ab]	1.34[b]	1.88[ab]	0.19	0.002
Ears, 0-7	1.07	1.14	1.59	1.63	0.17	0.92	0.86	1.35	1.62	1.60	0.17	0.08
Neck, 0-7	4.34	3.32	4.00	3.36	0.22	0.31	3.87	3.79	3.91	3.44	0.22	0.31
Shoulders, 0-7	4.60	4.48	4.56	4.31	0.22	0.73	4.42	4.66	4.42	4.45	0.22	0.57
Side, 0-7	4.87[a]	4.16[b]	4.24[ab]	4.51[ab]	0.22	0.01	4.75[a]	4.27[ab]	4.04[b]	4.71[ab]	0.22	0.002
Back, 0-7	2.92	1.08	2.31	1.11	0.20	0.06	1.87	2.13	1.88	1.54	0.20	0.07
Udder, 0-7	1.20	0.93	0.69	0.57	0.14	0.54	1.08	1.04	0.58	0.69	0.14	0.53
Rear, 0-7	3.23	1.38	3.07	1.27	0.21	0.87	2.26	2.35	2.17	2.17	0.21	0.78
Vulva, 0-7	0.51	0.24	0.52	0.30	0.11	0.80	0.61	0.15	0.46	0.35	0.11	0.06
Front Legs, 0-7	1.18	0.77	1.03	0.81	0.16	0.48	1.13	0.82	1.11	0.74	0.16	0.79
Hind Legs, 0-7	5.54[a]	3.77[c]	4.52[b]	3.95[bc]	0.23	0.002	4.80	4.51	4.26	4.21	0.23	0.51

[a-c] Means within a row with different superscripts differ ($P \leq 0.05$).

Table 2.5 Interactive effect of social status x feeding stall length on sow immune and endocrine measures (Least Square Means)

	Social Status*Feeding Stall Length					
	DOM		SUB			
Item	Long	Short	Long	Short	SE	P-value
Total WBC, 10^7	6.58	7.45	7.17	6.88	0.32	0.07
Lymphocyte, 10^7	4.12	4.12	4.71	3.99	0.39	0.71
Neutrophil, 10^7	20.99^{ab}	21.75^{ab}	23.29^{a}	17.97^{b}	1.19	0.04
Lymphocytes, %	47.53	42.20	47.07	46.50	1.35	0.08
Monocytes, %	2.11	2.02	1.97	2.53	0.23	0.09
Eosinophils, %	4.25	5.10	5.19	5.02	0.49	0.38
Segmented Neutrophils, %	0.42	0.50	0.65	1.17	0.16	0.21
Banded Neutrophils, %	45.66	50.14	45.10	44.71	0.45	0.09
Total Neutrophils, %	46.09	50.65	45.75	45.88	0.45	0.13
Neutrophil-to-Lymphoycte Ratio	1.27	1.56	1.18	1.23	0.10	0.23
ConA Proliferation, 2.0	1.01	1.01	1.01	1.02	0.01	0.27
ConA Proliferation, 20.0	1.03	1.03	1.03	1.04	0.01	0.86
LPS Proliferation, 5.0	1.06	1.07	1.08	1.07	0.02	0.71
LPS Proliferation, 50.0	1.09	1.11	1.13	1.13	0.03	0.65
Cortisol, ng/mL	16.01	16.82	13.92	15.40	1.17	0.80
IL-12, pg/mL	44.07	49.76	79.85	68.69	8.31	0.13
Blood Glucose, mg/dL	68.59^{b}	64.63^{c}	72.85^{a}	68.12^{b}	0.63	0.04

[a-c] Means within a row with different superscripts differ ($P \leq 0.05$).

Table 2.6 Interactive effect of diet x feeding stall length on aggressive behaviors registered during feedings (Least Square Means)

	Diet*Feeding Stall Length					
	Midds- Hulls		DDGS-GM			
Behavior	Long	Short	Long	Short	SE	P-value
Total Aggressive Encounters	17.69[b]	22.06[ab]	11.69[b]	29.56[a]	2.84	0.02
Total Displacements	1.88	13.50	2.94	21.44	2.13	0.58
AE:Disp	8.45[a]	1.69[b]	4.19[b]	1.62[b]	0.79	0.01
No. AE to SUB	8.50[a]	6.56[ab]	2.81[b]	7.75[a]	1.14	0.004
No. Displacements to SUB	1.50	4.25	0.63	5.19	0.85	0.19
No. AE by DOM	7.44	10.50	5.81	13.44	1.58	0.16
No. Displacements by DOM	1.00	8.44	1.19	11.06	1.16	0.30
No. AE by DOM to SUB	3.94	3.38	1.81	3.31	0.72	0.23
No. Disp by DOM to SUB	0.94	2.56	0.31	2.19	0.51	0.81

[a-b] Means within a row with different superscripts differ ($P \leq 0.05$).

Table 2.7 Interactive effect of feeding stall length x day post treatment on aggressive behaviors registered during feedings (Least Square Means)

	Feeding Stall Length*Day Post Stall Treatment									
	1		22		43		64			
Behavior	Long	Short	Long	Short	Long	Short	Long	Short	SE	P-value
Total Aggressive Encounters	22.38^{ab}	15.13^{ab}	15.75^{ab}	30.88^{a}	12.25^{b}	32.25^{a}	8.38^{b}	25.00^{ab}	4.01	0.003
Total Displacements	1.63	5.88	3.38	21.13	2.25	22.50	2.38	20.38	3.02	0.15
AE:Disp	10.92^{a}	2.27^{bc}	7.23^{ab}	1.58^{c}	4.09^{bc}	1.52^{c}	3.04^{bc}	1.25^{c}	1.12	0.04
No. AE to SUB	10.13^{a}	3.13^{b}	4.50^{ab}	8.13^{ab}	5.00^{ab}	9.88^{a}	3.00^{b}	7.50^{ab}	1.61	0.001
No. Displacements to SUB	1.00	1.38	1.00	4.88	1.00	6.50	1.25	6.13	1.20	0.13
No. AE by DOM	11.75^{ab}	6.38^{bc}	5.88^{bc}	13.88^{a}	4.25^{c}	14.25^{a}	4.63^{c}	13.38^{a}	2.24	0.004
No. Displacements by DOM	1.50^{c}	3.88^{bc}	1.00^{c}	11.13^{ab}	0.75^{c}	11.75^{a}	1.13^{c}	12.25^{a}	1.64	0.03
No. AE by DOM to SUB	6.13^{a}	1.25^{b}	1.63^{ab}	3.63^{ab}	2.00^{ab}	5.38^{ab}	1.75^{ab}	3.13^{ab}	1.02	0.002
No. Disp by DOM to SUB	0.88	0.75	0.50	2.13	0.25	3.88	0.88	2.75	0.71	0.09

[a-c] Means within a row with different superscripts differ (P ≤ 0.05).

Table 2.8 Interactive effects of social status x feeding stall length and social status x diet on behaviors registered during glucose collection (Least Square Means)

	Social Status*Feeding Stall Length						Social Status*Diet					
	DOM		SUB				DOM		SUB			
Behavior	Long	Short	Long	Short	SE	P-value	Midds-Hulls	DDGS-GM	Midds-Hulls	DDGS-GM	SE	P-value
Standing, %	24.95	30.80	27.35	33.96	2.10	0.97	36.84^{ab}	28.64^{b}	31.93^{ab}	38.89^{a}	3.49	0.02
Sitting, %	1.84	2.40	4.46	4.19	0.85	0.10	2.59^{b}	1.16^{b}	2.19^{b}	11.03^{a}	1.42	<.0001
Laying, %	5.93^{b}	7.76^{b}	7.45^{b}	14.95^{a}	1.52	0.05	8.45	9.70	13.72	11.82	2.42	0.54
ONF, %	28.84	26.30	32.08	26.16	2.11	0.18	20.29	24.54	21.16	16.78	3.45	0.15
Sham Chewing, %	23.95	19.42	13.61	14.78	1.74	0.22	18.04	21.58	12.97	13.76	2.90	0.56
Eating, %	10.00^{a}	6.68^{ab}	11.99^{a}	3.57^{b}	1.20	0.02	9.23^{b}	9.10^{b}	14.25^{a}	5.40^{b}	1.90	0.004
Drinking, %	4.02	6.43	3.00	2.06	0.92	0.13	4.19	5.13	3.20	2.59	1.54	0.59
Locomotion, %	0.46	0.30	0.10	0.26	0.26	0.82	0.17	-0.11	0.14	-0.35	0.44	0.80

[a-c] Means within a row with different superscripts differ (P ≤ 0.05)

Table 2.9 Interactive effect of social status x diet x feeding stall length on behaviors registered during glucose collection (Least Square Means)

	DOM				SUB					
	Long		Short		Long		Short			
Behavior	Midds-Hulls	DDGS-GM	Midds-Hulls	DDGS-GM	Midds-Hulls	DDGS-GM	Midds-Hulls	DDGS-GM	SE	P-value
Standing, %	31.77[a]	18.13[b]	35.19[a]	26.41[b]	31.66[a]	23.05[b]	30.08[a]	37.84[a]	2.95	0.006
Sitting, %	3.80	-0.13	2.58	2.22	1.61	7.32[a]	3.46	4.93	1.20	0.004
Laying, %	3.29	8.57	9.78	5.73	9.98	4.92	12.30	17.61	2.14	0.003
ONF, %	24.27	33.42	27.38	25.22	30.20	33.96	35.47	16.86	2.97	<.0001
Sham Chewing, %	25.54	22.36	10.37	28.46	8.47	18.75	12.14	17.42	2.44	<.0001
Eating, %	8.31	11.69	7.56	5.79	14.50	4.01	3.14	9.48	1.68	0.003
Drinking, %	2.36	5.68	6.65	6.20	3.25	2.75	2.73	1.39	1.29	0.67
Locomotion, %	0.60	0.32	0.59	0.01	0.40	-0.19	0.71	-0.19	0.37	0.96

[a-c] Means within a row with different superscripts differ ($P \leq 0.05$).

Table 2.10 Interactive effect of social status x time of feed delivery on behaviors registered during glucose collection (Least Square Means)

	DOM					SUB						
Behavior	30 min Prior	30 min Post	60 min Post	90 min Post	120 min Post	30 min Prior	30 min Post	60 min Post	90 min Post	120 min Post	SE	P-value
Standing, %	65.48[a]	9.84[b]	30.80[c]	30.28[c]	27.31[c]	52.44[c]	24.37[c]	32.09[c]	38.31[c]	29.84[c]	4.87	0.0001
Sitting, %	-0.18	-0.86	2.24	3.01	5.18	4.00	1.87	6.81	6.26	14.10	1.99	0.10
Laying, %	2.77	2.75	8.89	13.12	17.84	5.84	6.26	10.65	17.95	23.15	3.39	0.94
ONF, %	12.41	28.78	30.90	21.33	18.64	21.97	18.23	19.95	20.10	14.59	4.83	0.002
Sham Chewing, %	19.92	8.30	17.73	25.60	27.49	14.64	8.85	17.29	12.57	13.46	4.04	0.005
Eating, %	-0.19	40.79	4.04	2.44	-1.25	0.35	36.84	8.84	3.25	-0.16	2.67	0.15
Drinking, %	-0.43	10.12	4.86	4.15	4.61	0.58	3.50	3.93	1.46	5.01	2.14	0.03
Locomotion, %	0.38	-0.06	-0.36	0.24	-0.06	-0.04	-0.29	-0.29	0.05	0.05	0.62	0.96

[a-c] Means within a row with different superscripts differ ($P \leq 0.05$).

Chapter 3.

Social stress on well-being of gestating sows in group pens

Abstract

The effect of social status on the stress responsiveness and well-being of gestating sows housed in small group pens with feeding stalls and fed dietary fiber was assessed using multiple welfare metrics. At gestational d 37, groups of 9 multiparous sows/pen (n = 144 total sows; n = 36 sows/block) were randomly assigned by BW and parity to a 2 x 2 factorial arrangement of dietary treatment of either (**a**) soy hulls-wheat middlings diet (MIDDS-HULLS) or (**b**) DDGS-corn germ meal diet (DDGS-GM); and to a feeding stall length of either (**c**) 0.6 m (SHORT) or (**d**) 1.8 m (LONG). To determine social rank sows were subjected to a feed competition test; within each treatment pen a dominance value (DV) was calculated for each sow based on aggressive encounters during a feeding competition test. The two sows with the highest DV were identified as dominant (DOM) and two with the lowest DV were identified as submissive (SUB), this subpopulation of sows was used for analysis (n = 64). Sow BW, backfat (BF), body condition score (BCS) and blood samples were obtained on gestational d 30, 70, 90, 104, and d 131 (end of lactation). Body lesion scores and blood glucose levels (along with sow behavior) were recorded every 3 d for 2-wks post mixing (Phase 1), and then again on a bi-weekly basis until gestational d 104 (Phase 2). Live behavioral observations during feedings were registered at feeding post mixing (d 38), and then every 3-wk until gestational d 104, all aggressive encounters were recorded. Overall, lesion scores decreased in severity from phase 1 to phase 2, but in phase 2, DOM sows had less severe scores compared to SUB sows (P <0.01). DOM sows gained more (P < 0.01) BW from gestational d 30 till d 70. DOM sows had more (P <0.01) total piglets born and born alive, but higher (P < 0.01) overall mortality than did SUB sows. SUB sows had lower (P <0.04) N:L ratio than did DOM sows and higher (P <0.01) IL-12 concentrations. Percentages of time spent sitting and laying were greater (P <0.05) for SUB sows than DOM sows, while percentage of time spent sham-chewing was greater (P <0.01) for DOM sows. Socially, dominant and submissive sows both evoked different biological responses in order to adapt to their environments, there were no differences in litter-related traits. Although there was no effect on sow well-being by social rank, social status should be considered when implementing group housing as individual social rank evoke different biological responses to cope and adapt which may impact sow behavior, performance, and productivity.

Key Words: sow housing, social rank, stress response, well-being

INTRODUCTION

Some producers in the United States are transitioning from individual crates to loose housing systems due to consumer and legislative pressure. Thus, these decisions are not based on scientific evidence and the industry is moving forward without understanding the effect of social rank within sows on stress responsiveness and well-being in group housing. Group housing of gestating sows provides the opportunity for increased social interactions and exercise per se, but results in increased aggressive behavior in order to establish social hierarchy. Establishment of social hierarchy among group housed sows is inevitable and reduces overall aggression but can be stressful to sows (Beilharz and Cox, 1967).

Assessing stress is often challenging because there is inter-animal variability and other factors such as early experience, genetics, physiological state, and social relationships can affect the outcome (Moberg and Mench, 2000). Sows in kept in group housing may experience acute or chronic social stress, especially based on social status. Acute social stress is seen when animals are aggressive and chronic social stress is seen when animals are socially submissive (Morrow-Tesch et al., 1994). Social status of individual sows has been shown to affect behavior, physiology, performance, and productivity.

Other factors that should be considered when housing sows in groups are group size, space allowance, diet, and feeding system all of which can impact sow well-being. Feeding high dietary fiber to gestating sows can affect behavior, performance, and productivity (Robert et al., 1993; Brouns et al., 1994; de Leeuw et al., 2004; de Leeuw et al., 2005). Use of feeding stalls has been shown to decrease aggression and provide some protection to sows, which allows group sows to be fed individually (Andersen et al., 1999; O'Connell et al., 2003). Therefore, the objective of this study was to determine the effect of social status on the stress responsiveness

and well-being of gestating sows housed in small group pens equipped with feeding stalls and fed dietary fiber using multiple welfare metrics.

MATERIALS AND METHODS

Animals, Housing and Experimental Design

The University of Illinois Institutional Animal Care and Use Committee approved the protocol for this experiment. Primiparous (first-pregnancy gilts; *n*=39) and multiparous sows (parities 2 to ≥ 6; *n* = 104) derived from Genetiporc Fertilis 25 genetic lines were kept at the University of Illinois Swine Research Center between September 2013 and June 2015 (36/block). Once pregnancy was confirmed, groups of 9 sows were randomly allocated in a 2 x 2 factorial arrangement to group pens fitted with either a 0.6 m (**SHORT**) or 1.8 m (**LONG**) feeding stall and fed a modified gestation diet of either 30% wheat middlings-15% soy hulls which supplemented high fiber and low energy level (**MIDDS-HULLS**) or 30% DDGS-30% corn germ meal which supplemented high fiber and high energy level (**DDGS-GM**). Dietary treatments were initiated 2-d (d 35 post-breeding) prior to moving the group into treatment pens. All diets were formulated to meet or exceed NRC requirements (NRC, 2012). Sows were fed 2.23 kg/d MIDDS-HULLS diet from gestational d 35 to 90, and then from d 91 to 104 sows were fed 3.57 kg/d of the diet, while sows fed DDGS-GM diet were fed 2.10 kg/d from d 35 to 90 and 3.37 kg/d from d 91 to 104, respectively. All sows received 6,700 kcal ME/d from gestational d 35 to 90 and 10,720 kcal ME/d from d 91 to 104. Sows were moved to treatment group pens at gestational d 37 and housed in pens at a floor-space allowance 1.7 m^2 /sow (18 ft^2/sow). Feed was added to each feeding stall space within the group pen at 0630 h daily. Each feeding stall space was equipped with an individual nipple waterer and sows had ad libitum access to water.

All newly bred sows were kept in individual crates prior to the start of the study. Sows were AI within 24 h after the onset of estrus and then again 24 h later. Pregnancy was confirmed at d 27 post breeding using an EZ Preg Checker VSS700 (Veterinary Sales and Service Inc., Stuart FL.). On d 37, sows confirmed pregnant were moved to their assigned treatments and remained in their assigned treatment pens until approximately gestational d 104, when they were moved to a farrowing facility and remained until the end of lactation (d 131). Only 5 sows were removed from the study due to extreme lesions/injuries. All litters were weaned at 21 d of age ± 2, and sows were returned to the breeding facility. If cross-fostering was necessary, it occurred within same treatments.

Social Status

On gestational d 37 (prior to moving into treatment pens) post-feeding, groups of sows were placed in a non-experimental pen to determine social status using a feed competition test previously described by Parent et al. (2012). The non-experimental pen (4.10 m. x 4.10 m) was equipped with one feeder. The feed competition test was captured using EverFocus EQ120/AEN colored camera that was located above the pen and recorded using Geovision GVd1240 for 30 minutes. Initially, sows are acclimated to the non-experimental pen for 5-min, and then 4 kg of the assigned treatment diet was added to the feeder. All aggressive interactions were registered and both the initiator and the receiver during the aggressive encounters were identified. Behaviors registered during feeding competition test included fight, bite, push, chase, and displacement from feeder (Table 3.2). A Dominance Value (DV) was calculated for each sow based on all aggressive interactions that occurred during the feeding competition test. The equation was:

$$DV = \frac{Aggressive\ Encounters\ Initiated}{(Aggressive\ Encounters\ Initiated + Encounters\ Received)}$$

Based on the calculated DV and number of displacements that occurred in experimental pens, 2 sows per group were identified as dominant (**DOM**) and 2 sows were identified as submissive (**SUB**). This subsample of sows was analyzed separately and used for this analysis (*n*=64; primiparous *n*=21, multiparous *n*=43). After the feed competition, all sows were simultaneously moved to their assigned experimental pen.

Behavior

Sow behavior was captured using EverFocus EQ120/AEN colored cameras (EverFocus Co., LTD., Duarte, CA), Geovision GV-1240 (Geovision, Inc., Irvine, CA) video capture combo card, and viewed using EZViewLog (Geovision, Inc., Irvine, CA), cameras were fixed above each pen to view the entire area and lights were kept on 24 h a day. The Geovision combo card was programmed to record for the first 48 h after mixing and then again for 24 h on a bi-weekly basis. Live behavioral observations were registered during feeding at various time points including first feeding post-mixing, and then every 3-wk thereafter until sows were moved to farrowing facility to analyze aggressive behaviors that occur during feeding. Frequencies and durations of every aggressive encounter (AE) during these time periods was registered which included push, bite, fight, and threat, and for each encounter the initiating and receiving sow was registered (Table 3.2). At collection of blood glucose samples, posture and behavior for each sow was recorded to analyze possible correlations. Behaviors registered were eat, drink, sham chew, oral-nasal-facial (ONF), locomotion, stand, sit, and lay at blood glucose collection (Table 3.2).

Blood Sample Collection and Analysis

Blood samples were collected on gestational d 30, 70, 90, 104, and again at the end of lactation (~ 15 mL) ± 1 d via jugular venipuncture using 30 mL syringes containing 2 mL heparin. Sows were snared and blood samples were obtained > 2 mins. Whole blood smears were made, fixed in methanol, stained with Hema-3 staining system (Fisher Scientific, Houston, TX) and leukocyte differential counts were determined under a light microscope. Total white blood cell counts (WBC) were determined using a Coulter Z1 particle counter (Beckman Coulter, Miami, FL) by adding 10 µL of whole blood to 10 mL of Isoflow (Beckman Coulter) and 3 drops of Zap-oglobin (Beckman Coulter) to lyse red blood cells.

For functional immune assays, 12 mL of whole blood was carefully layered over Histopaque 1077 (density = 1.077 g/mL; Sigma Aldrich, Saint Louis, MO) and 1119 (density = 1.119 g/mL; Sigma Aldrich) and centrifuged for 30 minutes at 700 x g and 25° C. Mixed lymphocyte population was aspirated from the 1077 layer and neutrophils from the 1119 layer. The lymphocyte layer was washed with Roswell Park Memorial Institute media (RPMI; Gibco, Carlsbad, CA), centrifuged for 15 minutes at 1160 x g and 4° C, the pellet was then dissolved in RPMI/5% Fetal Bovine Serum (FBS) and incubated (37°C in a 5% CO_2 humidified incubator) in a petri dish for 1 h to isolate lymphocytes. After 1 h of incubation, non-adherent cells were washed in RPMI, resuspended in RPMI and counted (Beckman Coulter). Neutrophils were washed three times in RPMI, resuspended in Phosphate Buffered Saline (PBS; Fisher Scientific, Houston, TX) and counted (Beckman Coulter). Cell concentrations were adjusted for the specific requirements of each immune assay. Plasma was collected and stored at -20° C until further analysis.

Immune Assays

To assess innate immune status of sows, natural killer cell (NK) cytotoxicity and neutrophil chemotaxis were measured. Neutrophil chemotaxis was measured using an assay previously described by Salak et al. (1993) and Sutherland et al. (2005). Briefly, neutrophils were used at a concentration of 3 x 10^6 cells/mL, assay medium (RPMI) as a control and recombinant human complement-5a (10^{-5} M; Sigma Aldrich) was used as a chemoattractant. NK cell cytotoxicity was measured using a commercially available nonradioactive cytotoxicity detection kit (Roche Diagnostics, Indianapolis, IN), following the manufacture's protocol and as described by Sutherland et al. (2005) with modifications. Briefly, lymphocytes were used as effector cells and K-562 chronic human myelogenous leukemia cells (American Tissue Type Culture Collection, Manassas, VA) were used as target cells. Lymphocytes were adjusted to concentration of 1 x 10^7 cells/mL, K-562 cells were adjusted to a constant 10,000 cells/well, samples were run in triplicate at effector (lymphocytes) to target cell (K-562) ratios of 12.5:1, 25:1, 50:1, and 100:1. Plates were read using a microplate reader (Thermo Scientific Instruments, Waltham, MA) at a wavelength of 490 nm and reference wavelength of 690 nm. Percent cytotoxicity was calculated as described by Lumpkin and McGlone (1992), and an assay was considered valid if maximum release divided by spontaneous release was ≤ 30%.

To assess adaptive immune status of sows, mitogen induced lymphocyte proliferation assay was performed. Briefly, in triplicate, 100 μL of lymphocytes at a concentration of 5 x 10^6 cells/mL were added to a 96-well flat bottom plate. Concanavalin A (ConA; Sigma Aldrich) and lipopolysaccharide (LPS; Sigma Aldrich) were used as mitogens (ConA: 0, 2, and 20 μg/mL; LPS: 0, 5, and 50 μg/mL) to stimulate T and B cells, respectively. Plates were incubated for 48 h at 37°C in a 5% CO_2 humidified incubator, then 100 μL from each well was removed and 100 μL

of RPMI/10% FBS was added, plates were then incubated for 18 h. After 18 h incubation 20 μL of 3-[4, 5-dimethylthiazol-2-yl]-2, 5-diphenyltetrazolium bromide (MTT; Sigma Aldrich) was added to each well, and the plates were incubated for 4 h. Acidified isopropanol (100 μL of 0.1 N HCL in anhydrous isopropanol) was added to each well and plates were read within an hour using a microplate reader (Thermo Scientific Instruments) at a wavelength of 600 nm. The results are expressed as a proliferation index: Optical density of stimulated cells ÷ Optical density of nonstimulated cells.

Plasma Analysis

Total plasma cortisol was measured on d 30 (baseline) and d 90 of gestation using a commercially available RIA cortisol kit, following the manufacturer's protocol with exception of standards made in stripped porcine plasma (MP Biomedicals, Santa Ana, CA). Briefly, in duplicate, 25 μL of sample or standard were added to antibody-coated tubes. 1 mL of radiolabeled (I^{125}) cortisol was added to tubes, vortex, and incubated for 45 min in water bath at 37°C. The liquid phase was aspirated and radioactivity was counted with a gamma counter. A standard curve based on 0, 8, 16, 32, 62.5, 125, and 250 ng/μL was used. Intra- and interassay CV were 9.1% and 8.3% respectively, and sensitivity of 3 pg. Plasma IL-12 was measured on d 30 (baseline) and d 90 of gestation using a commercially available ELISA nonradioactive kit, following the manufacturer's protocol (R&D Systems, Minneapolis, MN). Briefly, in duplicates, 100 μL of diluted sample or standard and 50 μL of assay diluent was added to 96-well microplate coated with a monoclonal antibody specific for porcine IL-12/IL-23 p40. Plates were incubated for 2 h at room temperature on a horizontal orbital microplate shaker and then each well was aspirated and washed five times with wash buffer. Conjugate solution (200 μL) was added to

each well and incubated for another 2 h on the shaker. Each well was aspirated and washed five times, then 120 µL of substrate solution was added to each well and incubated for 30 min on the benchtop protected from light. After 30-min incubation, the reaction was stopped with 120 µL of stop solution to each well, and plates were read using a microplate reader (Thermo Scientific Instruments) at a wavelength 450 nm. A standard curve based on 0, 47, 94, 188, 375, 750, 1500, and 3000 pg/mL was used.

Blood Glucose Collection

Blood glucose levels were measured 2 d prior to and after treatment diets were fed, then every 3 d for the first two weeks post-mixing, and then again on a biweekly basis until sows were moved into farrowing crates. Blood glucose was measured 30 min prior to feeding and 30, 60, 90, and 120 min post feeding at each measurement day. The Precision Xtra monitor was used in combination with Precision Xtra strips (Abbott, Alameda, CA) to immediately determine the glucose level in a drop of blood as previously described by de Leeuw et al. (2005). A drop of blood was obtained from the ear vein using a small needle (20 gauge, 1 in.; Excel International). Samples that were not obtained within 5 min were excluded from the analysis.

Performance and Productivity Traits and Lesions Scores

Sow BW was taken on gestational d 30, 70, 90, 104, and end of lactation (~ d 131), ± 1 d. Sow backfat depth (BF) and body condition score (BCS) were taken on gestational d 30, 90, 104 and end of lactation ± 1 d. Sow BF depth was measured using a longitudinal imaging ultrasound scan cranial to the last rib using an Aloka-500V ultrasound machine (Hitachi Aloka, Walllingford, CT). Sow BCS was determined using visual-appraisal (sow's rear aspect) method

(1= emancipated to 5= obese) described by Coffey et al. (1999) and DeDecker et al. (2014). Body lesions scores were taken prior to moving into treatment pen (day 0), 1 d after mixing, and every 3 d for the first two weeks post-mixing (phase 1), and then on bi-weekly basis until gestational d 104, and again at the end of lactation (phase 2). Body lesion scores included hair coat condition, dung freedom, lameness, and various body regions. Body regions (Fig. 3.1) used to assess lesion scores included the head, ears, neck, chest/breast, shoulders, back, udder, rear, vulva, legs and hooves. Lesion scores were based on the presence or absence of an apparently new or old lesion in conjunction with severity of the wound (0 = normal/no lesions; 1 = dehairing, callus, balding; 2 = redness, swelling; 3 = swelling plus callus, abscess; 4 = moderate wound, scabbed over scratch; 5 = marked wound, fresh scratch; 6 = severe wound, open wound; and 7 = severe swelling). Averaging all scores from each body location for each sow resulted in a total body lesion severity score. Litter-related traits included total number of piglets born and born alive, and numbers of females, males, stillborn, mummified, laid on, euthanized, and total mortality (no. stillborn + no. mummified + no. laid on + no. euthanized), and piglets weaned. Calculated litter traits included litter BW at birth, adjusted litter BW at birth (adjusted by number of piglets born), litter wean BW, adjusted litter wean BW (adjusted by number of piglets weaned), and mean piglet weaning BW.

Statistical Analysis

Post hoc analysis was conducted on social status classification. All data were analyzed with the mixed models procedure of SAS (SAS Inst. Inc., Cary, NC), with repeated measures. All traits were tested for departures from normal distribution, and transformations were applied to traits deviating from normal distribution. A linear mixed-effects model was used to analyze

measurements, the model included all possible 2- and 3-way interactions of the fixed effects of diet (MIDDS-HULLS or DDGS-GM), feeding stall length (LONG or SHORT), and sow social status (DOM or SUB). A random effect of replicate was included in the model to account for potential environmental and management differences across groups. The model for physiological measures also included day of measurement (levels varies depending on measurement). The model for behaviors observed during feeding and blood glucose also included day post treatment (dietary or stall length treatment), which varied depending on measurement. Lesion scores being an ordinal variable required analysis with PROC GLIMMIX (SAS Inst. Inc., Cary, NC) to determine the means with a response distribution of Gaussian. Least square means were generated and separated statistically with pairwise *t* tests (PDIFF option). Significance was set at $P \leq 0.05$, whereas trends were discussed at $P \leq 0.10$.

RESULTS

Presented in Table 3.3 is the main effect of social status on body lesion scores. Total severity and ear lesion scores were greater ($P < 0.005$) for SUB sows than DOM sows. Socially, DOM sows had more severe ($P < 0.05$) udder and hind leg lesion scores and ($P < 0.09$) back lesion scores than did SUB sows (Table 3.3). Socially, DOM sows were heavier ($P < 0.03$) and gained more ($P < 0.05$) BW from gestational d 30 and 70 (Table 3.4), and tended to have greater ($P < 0.08$; Fig 3.2) mean BW than did SUB sows. Both, BF depth ($P < 0.09$) and BCS ($P < 0.0001$) were greater among DOM sows than SUB sows (Table 3.4). Socially, DOM sows had greater ($P < 0.01$) total piglets born and born alive than did SUB sows, but total piglet mortality was greater ($P < 0.05$) for DOM sows (Fig. 3.3). Also, DOM sows tended to farrow more ($P < 0.10$) female piglets and had heavier litters than did SUB sows (Table 3.5).

Socially, DOM sows had greater ($P < 0.04$) percentage of immature (banded) neutrophils and greater neutrophil-to-lymphocyte ratio (N:L) than did SUB sows, and tended to have greater ($P < 0.08$) percentage of total neutrophils (Table 3.6). While, SUB sows had greater percentage of segmented neutrophils and plasma IL-12 concentration than did DOM sows ($P < 0.01$; Fig. 3.4). Socially, SUB sows spent more ($P < 0.05$) time sitting and laying post-feeding than did DOM sows, and DOM sows spent more ($P < 0.01$) time sham-chewing than did SUB sows (Table 3.7).

DISCUSSION

The stress response is dependent on factors such as the type of stressor, duration (acute vs. chronic), and the animal's age, physiological state, and social relationships. These factors influence the animals' perception and the biological response that it will organize in its attempt to cope and adapt with the environment. These data imply that sow social status is an important factor to consider when managing sows in group housing systems, as individual social rank may evoke different biological responses to cope with social stress (e.g. dominant sows have greater BW and productivity) within a group-housing system.

This study shows that different biological responses are evoked on individual social rank. Socially, dominant sows may need to evoke greater stress responses when housed in group-pens with competitive feeding system to adapt and cope to their environment. Dominant sows continuously engaged in aggressive encounters during gestation, especially at feeding time to acquire resources (Chapter 2; Table 2.7). Socially, dominant sows spent less time sitting and laying, and had greater piglet mortality than submissive sows. This implies that dominant sows may divert energy allocation differently then submissive sows. It is plausible that dominant sows

divert their energy towards maintaining their social status during gestation, thus leads to greater piglet mortality. While, submissive sows may divert their energy to cope with aggressive interactions that lead to less BW gain, greater lesion scores, and decrease in litter productivity than dominant sows.

Previous studies have reported, in general, acute stress may suppress, enhance, or have no effect on the immune system, whereas chronic stress can often suppress the immune system, thus compromising animal health (Salak-Johnson and McGlone, 2007). Socially, submissive sows had lower N:L ratio and greater IL-12 levels than did dominant sows, which implies they may have been less stressed and other biological responses were sufficient to cope with the constraints. While dominant sows may have needed to evoke a physiological response in order to cope with their environment, thus being more stressed than submissive sows.

Assessing the stress response and well-being of group-kept sows requires an integrative approach of measuring behavioral, physiological, performance, and productivity traits in order to evaluate the animal's coping mechanism. While socially dominant and submissive sows had no impact on their well-being by having similar no. of piglets weaned and piglet weaning BW, the results of this study suggest dominant and submissive sows evoke different biological responses to cope and adapt to social stress within small group housing system. The different biological responses divert energy storage away from performance and productivity traits that may be consequential to the animal's well-being.

Implications

Social status should be considered when implementing group housing for sows, as individual social rank evokes different biological responses to cope and adapt to their

environment. These results indicated no impact on sow well-being, however further studies are needed to continue to investigate the effect of social stress on stress responsiveness and well-being based on social rank.

TABLES and FIGURES

Table 3.1 Composition of experimental diets fed to sows during gestation

Item	MIDDS-HULLS	DDGS-GM
Ingredients, %		
Corn	38.9	33.65
Soybean meal, 48%	12.5	2.5
Soybean hulls	15	-
Wheat middlings	30	-
DDGS	-	30
Corn germ meal	-	30
Soybean oil	1	1
Limestone	1.3	1.6
Dicalcium phosphate	0.6	0.55
Salt	0.4	0.4
Vitamin mineral premix	0.3	0.3
Total	100	100
Energy and nutrients		
Energy, Kcal ME/kg	2,999	3,177
Crude protein, %	13.78	18.96
Calcium, %	0.78	0.78
Phosphorus, %	0.61	0.66
Phosphorus, digestible, %	0.34	0.34
Acid detergent fiber, %	9.81	7.93
Neutral detergent fiber, %	23.97	25.75
Amino Acids[1]		
Arginine, %	0.9	0.83
Histidine, %	0.35	0.52
Isoleucine, %	0.59	0.49
Leucine, %	1.05	1.34
Lysine, %	0.61	0.61
Methionine, %	0.21	0.45
Methionine + cysteine, %	0.46	0.66
Phenylalanine, %	0.6	0.58
Threonine, %	0.43	0.51
Tryptophan, %	0.15	0.23
Valine, %	0.59	0.59

Table 3.2 Definitions of observed and registered behaviors

Behavior	Description
Aggressive Behaviors	
Bite	Opening and closing mouth near or on any part of another sow
Chase	Pursuit with the intent of further aggression to another sow
Push	Hitting another sow with head or snout
Fight	Vigorous reciprocated aggression (repeated biting and pushing)
Displacement	Physically and aggressively removing another sow from feeder, feeding stall, or pen area
Threat	Aggressive act but does not make any physical contact
Lay	Reclining in lateral or ventral position, no other behavior occurring
Sit	Supported by two front legs, no other behavior occurring
Stand	Supported by all four legs and no other behavior occurring
Locomotion	Sow is moving by supporting weight on one diagonal pair at a time
Eat	Snout/mouth in contact with feed or head is over or in the feeder when food is present
Drink	Snout/mouth in contact with the water nipple
Sham-chewing	Mouth empty while moving jaw in a repetitive chewing motion
Oral-nasal-facial	Snout or mouth in contact with any object besides food or water

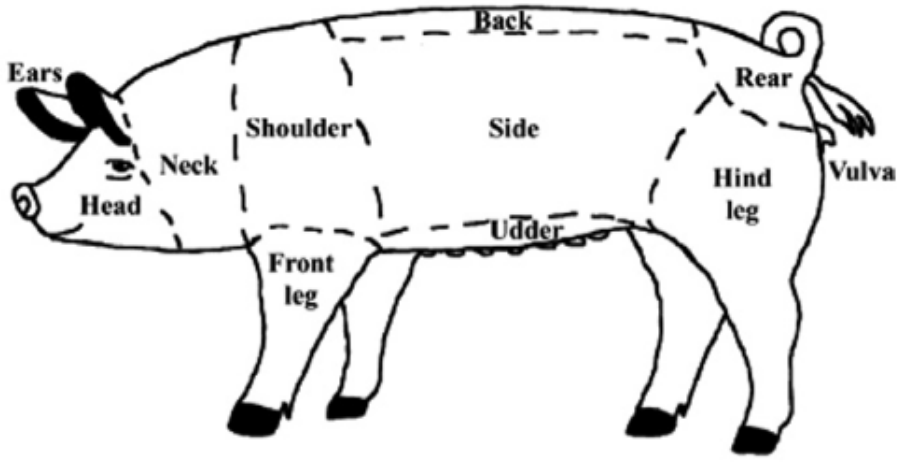

Figure 3.1 Schematic of body regions used to assess body lesion scores

Table 3.3 Main effect of social status on sow body lesion scores (Least Square Means)

Item	DOM	SUB	SE	P-value
Total Severity	25.58[b]	27.60[a]	0.61	0.005
Head, 0-7	1.87	1.61	0.16	0.12
Ears, 0-7	1.11[d]	1.61[c]	0.14	0.0006
Neck, 0-7	3.83	3.68	0.18	0.42
Shoulders, 0-7	4.54	4.44	0.17	0.57
Side, 0-7	4.51	4.37	0.18	0.47
Back, 0-7	2.00	1.71	0.16	0.09
Udder, 0-7	1.06[c]	0.63[d]	0.11	0.0003
Rear, 0-7	2.30	2.17	0.17	0.46
Vulva, 0-7	0.38	0.41	0.09	0.77
Front Legs, 0-7	0.97	0.92	0.12	0.70
Hind Legs, 0-7	4.66[a]	4.23[b]	0.18	0.03

[a,b] Means within a row with different superscripts differ ($P \leq 0.05$) and **[c,d]** differ ($P \leq 0.001$).

Table 3.4 Main effect of social status on sow performance (Least Square Means)

Item	DOM	SUB	SE	P-value
BW d 30, kg	233.13[c]	188.13[d]	3.09	<.0001
BW d 70, kg	225.60[a]	215.32[b]	2.68	0.03
BW d 90, kg	230.04	222.20	3.15	0.15
BW d 104, kg	249.54	238.78	3.87	0.11
BW d 135, kg	220.90	213.81	3.49	0.23
BW Mean, kg	229.43	222.17	2.33	0.08
BW Gain 1 (d 30 to 70), kg	12.97[a]	7.61[b]	1.92	0.05
BW Gain 2 (d 70 to 90), kg	3.62	4.61	0.93	0.45
BW Gain 3 (d 90 to 104), kg	19.08	17.00	0.95	0.13
BW Total Gain, kg	36.38	30.11	2.80	0.12
BW Loss, kg	-29.37	-25.13	2.86	0.28
BF Mean, cm	1.88[c]	1.69[d]	0.03	<.0001
BCS, 1-5	3.02	2.96	3.60	0.09

[a,b] Means within a row with different superscripts differ ($P \leq 0.05$) and **[c,d]** differ ($P \leq 0.001$).

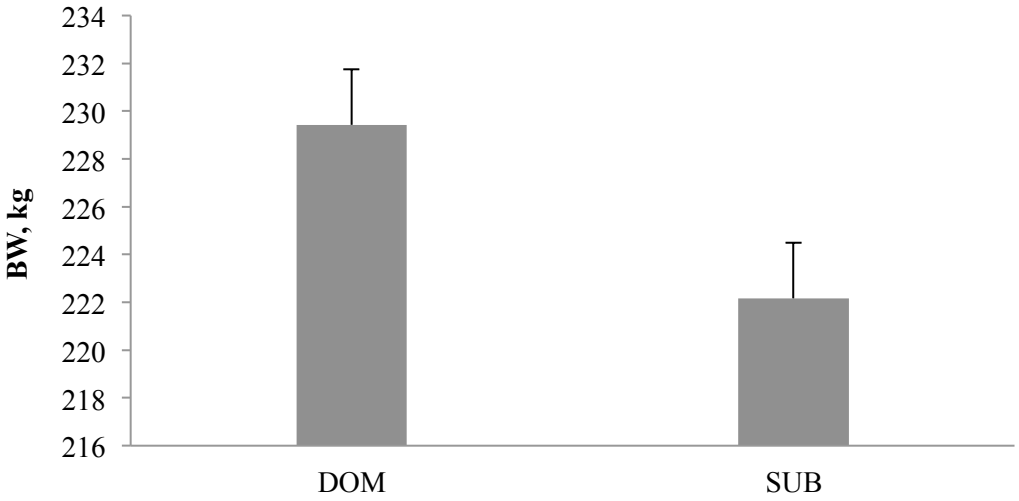

Figure 3.2 Social status effect on BW mean (P < 0.08)

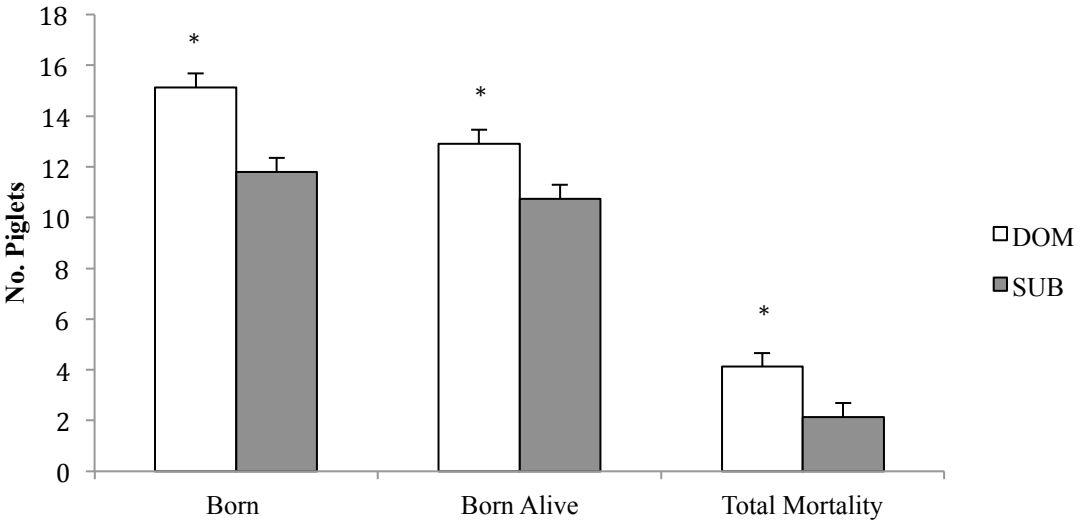

Figure 3.3 Social status effect on productivity (P < 0.01)

Table 3.5 Main effect of social status on sow productivity (Least Square Means)

	Social Status			
Item	DOM	SUB	SE	P-value
No. Born	15.13[a]	11.79[b]	0.67	0.001
No. Born Alive	12.92[a]	10.73[b]	0.57	0.01
No. Males	6.26	5.4	0.41	0.14
No. Females	6.06	5.01	0.41	0.07
No. Stillborns	2.02[a]	0.92[b]	0.35	0.03
No. Mummified	0.2	0.14	0.08	0.63
No. Laid On	0.8	0.65	0.2	0.28
No. Euthanized	1.11[a]	0.42[b]	0.19	0.02
No. Total Mortality	4.12[a]	2.13[b]	0.45	0.001
Litter Wt., kg	20.69	18.34	0.98	0.10
Adj. Litter Wt., kg	19.04	20.09	0.69	0.32
No. Weaned	10.52	10.01	0.37	0.33
Litter Wean Wt., kg	71.03	69.64	2.6	0.71
Adj. Litter Wean Wt., kg	69.53	71.34	1.29	0.33
Avg. Piglet Wean Wt., kg	6.76	7.04	0.13	0.14

[a,b] Means within a row with different superscripts differ ($P \leq 0.05$) and **[c,d]** differ ($P \leq 0.001$).

Table 3.6 Main effect of social status on immune and endocrine (Least Square Means)

Item	DOM	SUB	SE	P-value
Total WBC, 10^7	7.02	7.02	0.23	0.98
Lymphocyte, 10^7	4.12	4.35	0.28	0.63
Neutrophil, 10^7	21.37	20.63	0.85	0.34
Lymphocytes, %	44.87	46.79	0.97	0.16
Monocytes, %	2.07	2.25	0.16	0.44
Eosinophils, %	4.68	5.1	0.35	0.52
Segmented Neutrophils, %	0.46^b	0.91^a	0.11	0.01
Banded Neutrophils, %	47.90^a	44.91^b	1.03	0.04
Total Neutrophils, %	48.37	45.82	1.03	0.08
Neutrophil-to-Lymphoycte Ratio	1.41^a	1.20^b	0.07	0.04
ConA Proliferation, 2.0	1.01	1.02	0.01	0.48
ConA Proliferation, 20.0	1.03	1.03	0.01	0.61
LPS Proliferation, 5.0	1.06	1.08	0.01	0.58
LPS Proliferation, 50.0	1.1	1.13	0.02	0.43
Cortisol, ng/mL	16.41	14.66	0.83	0.13
IL-12, pg/mL	46.91^d	74.27^c	7.11	<.0001
Blood Glucose, mg/dL	67.43	68.93	0.66	0.11

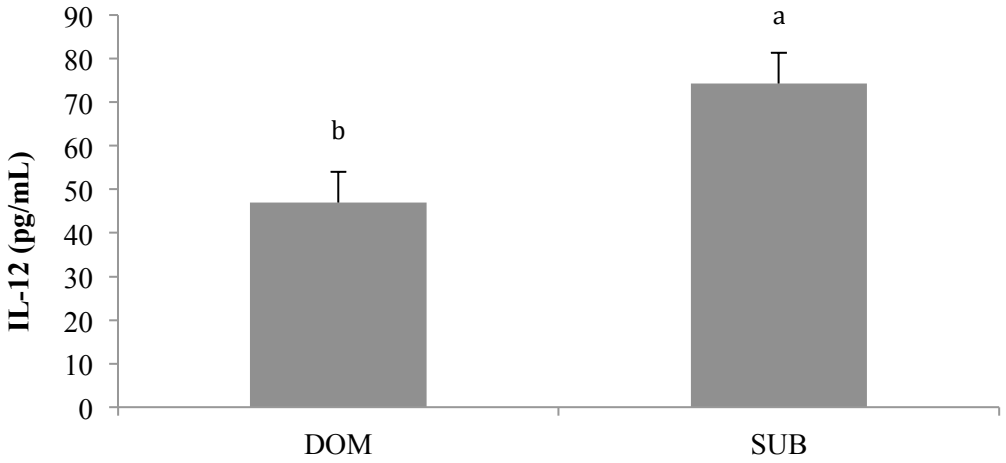

Figure 3.4 Social status effect on plasma IL-12 concentration ($P < 0.0001$)

Table 3.7 Effect of social status on behaviors (Least Square Means)

Behavior	DOM	SUB	SE	P-value
Stand				
Percentage, %	32.74	35.41	2.57	0.40
Frequency, no.	360	404		
Sit				
Percentage, %	1.88[d]	6.61[c]	1.05	0.0003
Frequency, no.	31	53		
Lay				
Percentage, %	9.07[b]	12.77[a]	1.78	0.05
Frequency, no.	83	150		
ONF				
Percentage, %	22.41	18.97	2.54	0.30
Frequency, no.	284	343		
Sham Chew				
Percentage, %	19.81[a]	13.36[b]	2.13	0.01
Frequency, no.	233	172		
Eat				
Percentage, %	9.17	9.83	1.4	0.88
Frequency, no.	95	111		
Drink				
Percentage, %	4.66	2.89	1.13	0.21
Frequency, no.	57	38		
Locomotion				
Percentage, %	0.03	-0.10	0.33	0.76
Frequency, no.	5	3		

[a,b] Means within a row with different superscripts differ ($P \leq 0.05$) and [c,d] differ ($P \leq 0.001$).
Total frequency = 2,422

LITERATURE CITED

Andersen, I. L., K. E. Bøe, and A. L. Kristiansen. 1999. The influence of different feeding arrangements and food type on competition at feeding in pregnant sows. Applied Animal Behaviour Science 65: 91-104.

Anil, L., S. S. Anil, J. Deen, S. K. Baidoo, and R. D. Walker. 2006. Effect of group size and structure on the welfare and performance of pregnant sows in pens with electronic sow feeders. Canadian Journal of Veterinary Research 70: 128-136.

Arey, D. S. 1999. Time course for the formation and disruption of social organisation in group-housed sows. Applied Animal Behaviour Science 62: 199-207.

Beilharz, R. G., and D. F. Cox. 1967. Social dominance in swine. Animal Behaviour 15: 117-122.

Broom, D. M., M. T. Mendl, and A. J. Zanella. 1995. A comparison of the welfare of sows in different housing conditions. Animal Science 61: 369-385.

Brouns, F., S. A. Edwards, and P. R. English. 1994. Effect of dietary fibre and feeding system on activity and oral behaviour of group housed gilts. Applied Animal Behaviour Science 39: 215-223.

Chapinal, N. et al., 2010. Aggressive Behavior in Two Different Group-Housing Systems for Pregnant Sows. Journal of Applied Animal Welfare Science 13: 137-153.

Coffey, R. D., G. Parker, and K. Laurent. 1999. Assessing sow body condition. ASC-158 Publication on-line at http://www. thepigsite. com/FeaturedArticle/Default. asp.

Council, F. A. W. 1993. Second Report on Priorities for Research and Development in Farm Animal Welfare. FAWC, Ministry of Agricultural, Fisheries and Food, Tolworth (Now DEFRA, London).

Csermely, D., and D. G. M. Wood-Gush. 1990. Agonistic behaviour in grouped sows. II. How social rank affects feeding and drinking behaviour. Bolletino di zoologia 57: 55-58.

Curtis, S. E. 2009. Environmental Aspects of Animal Care: Applied Ecology in the Husbandry of Kept Animals. 1: 81-85.

da Silva, C. S., J. J. van den Borne, W. J. Gerrits, B. Kemp, and J. E. Bolhuis. 2012. Effects of dietary fibers with different physicochemical properties on feeding motivation in adult female pigs. Physiology & behavior 107: 218-230.

Danielsen, V., and E.-M. Vestergaard. 2001. Dietary fibre for pregnant sows: effect on performance and behaviour. Animal Feed Science and Technology 90: 71-80.

de Leeuw, J. A., A. W. Jongbloed, and M. W. A. Verstegen. 2004. Dietary Fiber Stabilizes Blood Glucose and Insulin Levels and Reduces Physical Activity in Sows (Sus scrofa). Journal of Nutrition 134: 1481-1486.

de Leeuw, J. A. et al. 2005. Effects of levels and sources of dietary fermentable non-starch polysaccharides on blood glucose stability and behaviour of group-housed pregnant gilts. Applied Animal Behaviour Science 94: 15-29.

DeDecker, A. E., A. R. Hanson, P. M. Walker, and J. L. Salak-Johnson. 2014. Space allowance and high fiber diet impact performance and behavior of group-kept gestating sows. Journal of Animal Science 92: 1666-1674.

Dhabhar, F. S. 2014. Effects of stress on immune function: the good, the bad, and the beautiful. Immunologic research 58: 193-210.

Elmore, M. R. P. et al., 2011. Getting around social status: Motivation and enrichment use of dominant and subordinate sows in a group setting. Applied Animal Behaviour Science 133: 154-163.

Guillemet, R. et al., 2007. Dietary fibre for gestating sows: effects on parturition progress, behaviour, litter and sow performance. animal 1: 872-880.

Hemsworth, P. H. et al., 2013. Effects of group size and floor space allowance on grouped sows: Aggression, stress, skin injuries, and reproductive performance. Journal of Animal Science 91: 4953-4964.

Holt, J. P., L. J. Johnston, S. K. Baidoo, and G. C. Shurson. 2006. Effects of a high-fiber diet and frequent feeding on behavior, reproductive performance, and nutrient digestibility in gestating sows. Journal of Animal Science 84: 946-955.

Hoy, S., J. Bauer, C. Borberg, L. Chonsch, and C. Weirich. 2009. Impact of rank position on fertility of sows. Livestock Science 126: 69-72.

Johnston, L. 2010. Gestating Swine Nutrient Recommendations and Feeding Management.

Knox, R., J. Salak-Johnson, M. Hopgood, L. Greiner, and J. Connor. 2014. Effect of day of mixing gestating sows on measures of reproductive performance and animal welfare. Journal of Animal Science 92: 1696-1705.

Levine, S. 2005. Chapter 1.1 - Stress: an historical perspective. In: N. H. K. T. Steckler and J. M. H. M. Reul (eds.) Techniques in the Behavioral and Neural Sciences No. Volume 15, Part 1. p 3-23. Elsevier.

Li, Y., and H. Gonyou. 2013. Comparison of management options for sows kept in pens with electronic feeding stations. Canadian Journal of Animal Science 93: 445-452.

Lumpkin, E. A., and J. J. McGlone. 1992. A 51Cr Release Assay for the Determination of Natural Killer Cell Cytotoxicity. Journal of Nutritional Immunology 1: 63-74.

Mack, L. A. et al., 2014. Group space allowance has little effect on sow health, productivity, or welfare in a free-access stall system. Journal of Animal Science 92: 2554-2567.

Matte, J. J., S. Robert, C. L. Girard, C. Farmer, and G. P. Martineau. 1994. Effect of bulky diets based on wheat bran or oat hulls on reproductive performance of sows during their first two parities. Journal of animal science 72: 1754-1760.

McEwen, B. S. 2000. Stress, definition and concepts of. Encyclopedia of stress 3: 508-509.

McGlone, J., and S. Fullwood. 2001. Behavior, reproduction, and immunity of crated pregnant gilts: effects of high dietary fiber and rearing environment. JOURNAL OF ANIMAL SCIENCE-MENASHA THEN ALBANY THEN CHAMPAIGN ILLINOIS- 79: 1466-1474.

McInerney, J. 1998. The economics of Welfare.

Mepham, B. 1996. Ethical Analysis of Food Biotechnologies: an Evaluative Framework. Food Ethics: 101-119.

Moberg, G. 1987. Problems in defining stress and distress in animals. Journal of the American Veterinary Medical Association 191: 1207-1211.

Moberg, G. P., and J. A. Mench. 2000. The biology of animal stress: basic principles and implications for animal welfare. CABI.

Morrow-Tesch, J. L., J. J. McGlone, and J. L. Salak-Johnson. 1994. Heat and social stress effects on pig immune measures. Journal of animal science 72: 2599-2609.

NRC. 2012. Nutrient Requirements of Swine: Eleventh Revised Edition, Washington, DC.

O'Connell, N. E., V. E. Beattie, and B. W. Moss. 2003. Influence of social status on the welfare of sows in static and dynamic groups. Animal Welfare 12: 239-249.

Parent, J.-P., M.-C. Meunier-Salaün, E. Vasseur, and R. Bergeron. 2012. Stability of social hierarchy in growing female pigs and pregnant sows. Applied Animal Behaviour Science 142: 1-10.

Pond, W. G., F. W. Bazer, and B. E. Rollin. 2012. Animal welfare in animal agriculture : husbandry, stewardship, and sustainability in animal production. CRC Press, Boca Raton, FL.

Quesnel, H. et al., 2009. Dietary fiber for pregnant sows: Influence on sow physiology and performance during lactation. Journal of Animal Science 87: 532-543.

Remience, V. et al., 2008. Effects of space allowance on the welfare of dry sows kept in dynamic groups and fed with an electronic sow feeder. Applied Animal Behaviour Science 112: 284-296.

Robert, S., J. J. Matte, C. Farmer, C. L. Girard, and G. P. Martineau. 1993. High-fibre diets for sows: effects on stereotypies and adjunctive drinking. Applied Animal Behaviour Science 37: 297-309.

Rollin, B. E. 1993. Animal welfare, science, and value. Journal of Agricultural and Environmental Ethics 1993.

Salak, J. L., J. J. McGlone, and M. Lyte. 1993. Effects of in vitro adrenocorticotrophic hormone, cortisol and human recombinant interleukin-2 on porcine neutrophil migration and luminol-dependent chemiluminescence. Veterinary Immunology and Immunopathology 39: 327-337.

Salak-Johnson, J. L., A. E. DeDecker, M. J. Horsman, and S. L. Rodriguez-Zas. 2012. Space allowance for gestating sows in pens: Behavior and immunity. Journal of Animal Science 90: 3232-3242.

Salak-Johnson, J. L., and J. J. McGlone. 2007. Making sense of apparently conflicting data: Stress and immunity in swine and cattle. Journal of Animal Science 85: E81-E88.

Salak-Johnson, J. L., S. R. Niekamp, S. L. Rodriguez-Zas, M. Ellis, and S. E. Curtis. 2007. Space allowance for dry, pregnant sows in pens: Body condition, skin lesions, and performance. Journal of Animal Science 85: 1758-1769.

Schulkin, J. 2004. Allostasis, homeostasis and the costs of physiological adaptation. Cambridge University Press, Cambridge UK ; New York.

Smith, S. M., and W. W. Vale. 2006. The role of the hypothalamic-pituitary-adrenal axis in neuroendocrine responses to stress. Dialogues in clinical neuroscience 8: 383.

Sterling, P., and J. Eyer. 1988. Allostasis: a new paradigm to explain arousal pathology.

Strawford, M. L., Y. Z. Li, and H. W. Gonyou. 2008. The effect of management strategies and parity on the behaviour and physiology of gestating sows housed in an electronic sow feeding system. Canadian Journal of Animal Science 88: 559-567.

Sutherland, M. A., S. R. Niekamp, S. L. Rodriguez-Zas, and J. L. Salak-Johnson. 2006. Impacts of chronic stress and social status on various physiological and performance measures in pigs of different breeds. Journal of Animal Science 84: 588-596.

Sutherland, M. A., S. L. Rodriguez-Zas, M. Ellis, and J. L. Salak-Johnson. 2005. Breed and age affect baseline immune traits, cortisol, and performance in growing pigs. Journal of Animal Science 83: 2087-2095.

Terlouw, E. M. C., and A. B. Lawrence. 1993. Long-term effects of food allowance and housing on development of stereotypies in pigs. Applied Animal Behaviour Science 38: 103-126.

Terlouw, E. M. C., A. B. Lawrence, and A. W. Illius. 1991. Influences of feeding level and physical restriction on development of stereotypies in sows. Animal Behaviour 42: 981-991.

Terlouw, E. M. C., A. B. Lawrence, J. M. Koolhaas, and M. Cockram. 1993. Relationship between feeding, stereotypies, and plasma glucose concentrations in food-restricted and restrained sows. Physiology and Behavior 54: 189-193.

Tönepöhl, B., A. K. Appel, B. Voß, U. König von Borstel, and M. Gauly. 2013. Interaction between sows' aggressiveness post mixing and skin lesions recorded several weeks later. Applied Animal Behaviour Science 144: 108-115.

Tuchscherer, M., B. Puppe, A. Tuchscherer, and E. Kanitz. 1998. Effects of social status after mixing on immune, metabolic, and endocrine responses in pigs. Physiology & Behavior 64: 353-360.

Weng, R. C., S. A. Edwards, and P. R. English. 1998. Behaviour, social interactions and lesion scores of group-housed sows in relation to floor space allowance. Applied Animal Behaviour Science 59: 307-316.

Whittaker, X., S. Edwards, H. Spoolder, A. Lawrence, and S. Corning. 1999. Effects of straw bedding and high fibre diets on the behaviour of floor fed group-housed sows. Applied Animal Behaviour Science 63: 25-39.

Whittaker, X., H. Spoolder, S. Edwards, A. Lawrence, and S. Corning. 1998. The influence of dietary fibre and the provision of straw on the development of stereotypic behaviour in food restricted pregnant sows. Applied Animal Behaviour Science 61: 89-102.

Zhao, Y., W. L. Flowers, A. Saraiva, K. J. Yeum, and S. W. Kim. 2013. Effect of social ranks and gestation housing systems on oxidative stress status, reproductive performance, and immune status of sows. Journal of Animal Science 91: 5848-5858.

APPENDIX A

Table A.1 Social status × diet × feeding stall length on sow performance (Least Square Means)

	DOM				SUB					
	Long		Short		Long		Short			
Item	Midds-Hulls	DDGS-GM	Midds-Hulls	DDGS-GM	Midds-Hulls	DDGS-GM	Midds-Hulls	DDGS-GM	SE	P-value
BW d 30, kg	251.88[a]	233.75[ab]	218.44[bc]	228.44[ab]	181.69[d]	185.19[d]	198.94[cd]	186.69[d]	6.19	0.04
BW d 70, kg	223.96	223.71	222.80	231.95	219.49	217.49	217.99	206.32	4.27	0.26
BW d 90, kg	227.16	226.08	227.11	239.81	227.02	222.76	227.54	211.47	5.12	0.17
BW d 104, kg	249.10	245.09	245.69	258.27	245.14	238.44	247.39	224.12	6.29	0.15
BW d 135, kg	213.01	221.08	219.42	230.09	215.10	216.07	215.31	208.74	5.67	0.75
BW Mean, kg	228.05	226.69	226.82	236.16	225.72	222.49	226.69	213.76	3.79	0.13
BW Gain 1 (d 30 to 70), kg	9.32	11.00	11.75	19.81	12.44	10.06	9.06	-1.12	3.83	0.43
BW Gain 2 (d 70 to 90), kg	3.65	2.25	3.81	4.78	6.13	3.94	6.26	2.12	1.85	0.71
BW Gain 3 (d 90 to 104), kg	21.15	18.56	18.44	18.15	18.69	16.19	20.06	13.07	1.90	0.42
BW Total Gain, kg	34.00	31.81	34.00	45.71	37.25	30.19	37.58	15.43	5.57	0.20
BW Loss, kg	-35.08	-24.50	-29.38	-28.52	-27.71	-24.39	-32.55	-15.87	5.53	0.33
BF Mean, cm	1.79	1.99	1.85	1.91	1.73	1.76	1.68	1.59	0.05	0.26
BCS, 1-5	3.12	2.97	2.99	3.00	2.94	2.98	2.96	2.97	3.60	0.25

[a-c] within a row, means with different superscript differ at ($P \leq 0.05$).

Table A.2 Social status × diet × feeding stall length on body lesion scores (Least Square Means)

	DOM				SUB					
	Long		Short		Long		Short			
Item	Midds-Hulls	DDGS-GM	Midds-Hulls	DDGS-GM	Midds-Hulls	DDGS-GM	Midds-Hulls	DDGS-GM	SE	P-value
Total Severity	27.17^{abc}	30.52^{a}	23.79^{cd}	20.85^{d}	29.33^{ab}	29.60^{ab}	26.31^{bc}	25.16^{c}	1.01	0.003
Head, 0-7	2.27	1.94	1.94	1.33	1.30	2.08	1.38	1.68	0.25	0.50
Ears, 0-7	0.83	1.31	0.90	1.39	1.59	1.58	1.65	1.61	0.22	1.00
Neck, 0-7	4.18	4.51	3.57	3.07	4.28	3.71	3.54	3.18	0.29	0.27
Shoulders, 0-7	4.40	4.80	4.44	4.52	4.44	4.69	4.41	4.22	0.29	0.59
Side, 0-7	4.97	4.76	4.53	3.78	3.94	4.54	4.14	4.88	0.29	0.58
Back, 0-7	2.69^{ab}	3.15^{a}	1.04^{c}	1.12^{c}	2.78^{ab}	1.83^{bc}	0.98^{c}	1.25^{c}	0.26	0.03
Udder, 0-7	1.13	1.27	1.04	0.82	0.64	0.75	0.52	0.62	0.18	0.54
Rear, 0-7	3.01	3.45	1.50	1.26	3.14	3.00	1.21	1.34	0.28	0.36
Vulva, 0-7	0.82	0.21	0.40	0.09	0.51	0.52	0.41	0.19	0.14	0.35
Front Legs, 0-7	1.14^{ab}	1.22^{ab}	1.11^{ab}	0.43^{b}	1.34^{a}	0.72^{ab}	0.88^{ab}	0.75^{ab}	0.20	0.05
Hind Legs, 0-7	5.75	5.33	3.86	3.68	4.49	4.55	4.02	3.88	0.30	0.85

[a-c] Means within a row with different superscripts differ ($P \leq 0.05$).

Table A.3 Interactive effects of social status × feeding stall length and social status × diet on sow productivity (Least Square Means)

	Social Status*Feeding Stall Length						Social Status*Diet					
	DOM		SUB				DOM		SUB			
Item	Long	Short	Long	Short	SE	P-value	Midds-Hulls	DDGS-GM	Midds-Hulls	DDGS-GM	SE	P-value
No. Born	15.6	14.67	11.59	12	0.95	0.48	15.17	15.1	12.55	11.04	0.95	0.45
No. Born Alive	13.09	12.75	11.11	10.34	0.79	0.80	12.79	13.04	11.19	10.28	0.79	0.47
No. Males	5.52	7	5.57	5.24	0.57	0.12	5.85	6.68	5.8	5.1	0.57	0.16
No. Females	6.79	5.33	5.31	4.71	0.57	0.46	6.56	5.56	5.1	4.92	0.57	0.48
No. Stillborns	2.29	1.75	0.39	1.46	0.49	0.11	2.18	1.86	1.17	0.68	0.49	0.87
No. Mummified	0.23	0.17	0.09	0.19	0.12	0.51	0.2	0.2	0.2	0.08	0.12	0.62
No. Laid On	0.86	0.75	0.78	0.52	0.28	0.59	0.81	0.8	0.54	0.76	0.28	0.71
No. Euthanized	1.63	0.58	0.5	0.34	0.27	0.12	1.03	1.18	0.37	0.47	0.27	0.71
No. Total Mortality	5	3.25	1.8	2.5	0.63	0.11	4.22	4.03	2.27	1.98	0.64	0.71
Litter Wt., kg	20.72	20.67	19.65	17.04	1.38	0.36	20.24	21.15	17.99	18.69	1.38	0.94
Adj. Litter Wt., kg	18.56	19.51	21.37	18.81	0.95	0.06	18.54	19.53	19.15	21.03	0.94	0.63
No. Weaned	10.54	10.5	9.58	10.43	0.52	0.40	10.64	10.4	10.25	9.76	0.52	0.81
Litter Wean Wt., kg	71.11	70.96	70.52	68.75	3.67	0.83	69.82	72.24	70.04	69.23	3.68	0.66
Adj. Litter Wean Wt., kg	69.47	69.58	74.87	67.81	1.81	0.06	67.59	71.47	70.23	72.45	1.81	0.65
Avg. Piglet Wean Wt., kg	6.74^{ab}	6.77^{ab}	7.40^{a}	6.68^{b}	0.18	0.05	6.58	6.93	6.92	7.16	0.18	0.77

[a-c] Means within a row with different superscripts differ ($P \leq 0.05$).

Table A.4 Social status × diet × feeding stall length on sow productivity (Least Square Means)

	DOM				SUB					
	Long		Short		Long		Short			
Item	Midds-Hulls	DDGS-GM	Midds-Hulls	DDGS-GM	Midds-Hulls	DDGS-GM	Midds-Hulls	DDGS-GM	SE	P-value
No. Born	17.00	14.20	13.33	16.00	11.83	11.34	13.26	10.74	1.34	0.11
No. Born Alive	14.09	12.09	11.50	14.00	11.33	10.88	11.04	9.68	1.12	0.13
No. Males	5.52	5.52	6.17	7.83	5.83	5.31	5.77	4.71	0.80	0.55
No. Females	7.79	5.79	5.33	5.33	5.50	5.12	4.70	4.72	0.80	0.45
No. Stillborns	2.69	1.89	1.67	1.83	0.50	0.28	1.83	1.08	0.69	0.72
No. Mummified	0.23	0.23	0.17	0.17	-5.00E-16	0.18	0.40	-0.02	0.17	0.22
No. Laid On	0.96	0.76	0.67	0.83	0.50	1.06	0.59	0.46	0.40	0.69
No. Euthanized	1.73	1.53	0.33	0.83	0.33	0.67	0.40	0.27	0.39	0.68
No. Total Mortality	5.60	4.40	2.83	3.67	1.33	2.18	3.22	1.78	0.90	0.22
Litter Wt., kg	21.03	20.41	19.45	21.89	17.74	21.55	18.25	15.83	1.95	0.23
Adj. Litter Wt., kg	17.32	19.80	19.77	19.26	19.72	23.02	18.59	19.03	1.32	0.29
No. Weaned	10.94	10.14	10.33	10.67	10.00	9.16	10.50	10.36	0.73	0.66
Litter Wean Wt., kg	70.81	71.41	68.83	73.08	67.92	73.13	72.16	65.33	5.19	0.49
Adj. Litter Wean Wt., kg	66.68^{b}	72.26^{ab}	68.50^{ab}	70.67^{ab}	69.65^{ab}	80.09^{a}	70.81^{ab}	64.82^{b}	2.56	0.01
Avg. Piglet Wean Wt., kg	6.50^{b}	6.99^{ab}	6.67^{b}	6.87^{ab}	6.82^{ab}	7.99^{a}	7.02^{ab}	6.33^{b}	0.26	0.005

[a-c] Means within a row with different superscripts differ ($P \leq 0.05$).

Table A.5 Interactive effect of social status × diet on immune and endocrine (Least Square Means)

	Social Status*Diet					
	DOM		SUB			
Item	Midds-Hulls	DDGS-GM	Midds-Hulls	DDGS-GM	SE	P-value
Total WBC, 10^7	6.53	7.5	6.86	7.18	0.32	0.31
Lymphocyte, 10^7	4.09	4.15	4.39	4.31	0.39	0.90
Neutrophil, 10^7	21.87	20.87	20.95	20.31	1.19	0.83
Lymphocytes, %	43.85	45.88	46.02	47.55	1.36	0.85
Monocytes, %	2.47^{a}	1.67^{b}	2.24^{ab}	2.26^{ab}	0.23	0.03
Eosinophils, %	4.90	4.45	5.36	4.85	0.49	0.79
Segmented Neutrophils, %	0.53	0.40	1.03	0.79	0.16	0.51
Banded Neutrophils, %	48.18	47.62	45.32	44.49	1.45	0.92
Total Neutrophils, %	48.71	48.02	46.36	45.28	1.45	0.89
Neutrophil-to-Lymphoycte Ratio	1.49	1.34	1.26	1.14	0.10	0.88
ConA Proliferation, 2.0	1.01	1.00	1.01	1.02	0.01	0.34
ConA Proliferation, 20.0	1.05	1.01	1.05	1.02	0.01	0.61
LPS Proliferation, 5.0	1.08	1.05	1.10	1.05	0.02	0.65
LPS Proliferation, 50.0	1.11	1.09	1.17	1.09	0.03	0.54
Cortisol, ng/mL	16.93	15.89	14.59	14.73	1.17	0.77
IL-12, pg/mL	41.78	52.04	76.38	72.16	8.31	0.31
Blood Glucose, mg/dL	68.38	66.49	68.22	69.64	0.92	0.07

Table A.6 Social status × diet × feeding stall length on immune and endocrine (Least Square Means)

	DOM				SUB					
	Long		Short		Long		Short			
Item	Midds-Hulls	DDGS-GM	Midds-Hulls	DDGS-GM	Midds-Hulls	DDGS-GM	Midds-Hulls	DDGS-GM	SE	P-value
Total WBC, 10^7	5.96	7.20	7.11	7.79	6.97	7.37	6.76	7.00	0.45	0.81
Lymphocyte, 10^7	3.99	4.25	4.18	4.05	4.88	4.54	3.90	4.08	0.55	0.15
Neutrophil, 10^7	20.43	21.54	23.30	20.19	23.58	23.00	18.32	17.62	1.69	0.65
Lymphocytes, %	48.12	46.94	39.58	44.82	47.77	46.38	44.28	48.72	1.91	0.08
Monocytes, %	2.58	1.65	2.36	1.68	2.11	1.84	2.36	2.69	0.33	0.47
Eosinophils, %	4.32	4.17	5.47	4.74	5.27	5.11	5.45	4.58	0.7	0.90
Segmented Neutrophils, %	0.47	0.37	0.58	0.43	0.90	0.40	1.16	1.18	0.23	0.90
Banded Neutrophils, %	44.44	46.88	51.92	48.36	44.02	46.18	46.63	42.80	2.04	0.12
Total Neutrophils, %	44.91	47.26	52.51	48.79	44.92	46.59	47.79	43.97	2.04	0.14
Neutrophil-to-Lymphoycte Ratio	1.18^{ab}	1.35^{ab}	1.79^{a}	1.32^{ab}	1.14^{b}	1.21^{ab}	1.39^{ab}	1.07^{b}	0.14	0.04
ConA Proliferation, 2.0	1.02	1.01	1.01	1.00	1.00	1.01	1.02	1.03	0.01	0.99
ConA Proliferation, 20.0	1.04	1.01	1.06	1.00	1.04	1.02	1.06	1.02	0.02	0.76
LPS Proliferation, 5.0	1.07	1.04	1.09	1.05	1.10	1.05	1.10	1.04	0.03	0.92
LPS Proliferation, 50.0	1.11	1.06	1.11	1.12	1.17	1.09	1.17	1.09	0.05	0.83
Cortisol, ng/mL	18.07	13.94	15.79	17.85	15.18	12.65	14.00	16.81	1.65	0.08
IL-12, pg/mL	42.38	45.75	41.19	58.34	85.39	74.31	67.38	70.00	10.29	0.38
Blood Glucose, mg/dL	70.25	66.93	64.60	64.66	72.76	72.94	68.79	67.44	0.89	0.14

[a-b] Means within a row with different superscripts differ ($P \leq 0.05$).

Table A.7 Interactive effect of day post stall treatment × diet on behaviors registered during feedings (Least Square Means)

	Day Post Stall Treatment*Diet									
	1		22		43		64			
Behavior	Midds-Hulls	DDGS-GM	Midds-Hulls	DDGS-GM	Midds-Hulls	DDGS-GM	Midds-Hulls	DDGS-GM	SE	P-value
Total Aggressive Encounters	22.88	14.63	20.63	26.00	20.63	23.88	15.38	18.00	4.01	0.50
Total Displacements	4.00	3.50	7.25	17.25	10.63	14.13	8.88	13.88	3.02	0.73
AE:Disp	8.69	4.50	5.62	3.19	3.41	2.20	2.55	1.75	1.12	0.58
No. AE to SUB	9.88	3.38	6.63	6.00	8.88	6.00	4.75	5.75	1.61	0.12
No. Displacements to SUB	1.63	0.75	2.00	3.88	4.38	3.13	3.50	3.88	1.20	0.34
No. AE by DOM	10.38	7.75	7.13	12.63	9.50	9.00	8.88	9.13	2.24	0.32
No. Displacements by DOM	2.25	3.13	4.75	7.38	5.88	6.63	6.00	7.38	1.64	0.94
No. AE by DOM to SUB	5.00	2.38	2.88	2.38	4.13	3.25	2.63	2.25	1.02	0.90
No. Disp by DOM to SUB	0.88	0.75	1.50	1.13	2.38	1.75	2.25	1.38	0.71	0.96

APPENDIX B

Table B.1 Main effects of diet and feeding stall length on sow performance (Least Square Means)

	Diet				Feeding Stall Length			
Item	Midds-Hulls	DDGS-GM	SE	P-value	Long	Short	SE	P-value
BW d 30, kg	212.73	208.52	3.09	0.34	213.13	208.13	3.09	0.26
BW d 70, kg	221.06	219.87	1.91	0.66	221.16	219.76	1.92	0.61
BW d 90, kg	227.21	225.03	2.29	0.51	225.75	226.48	2.29	0.82
BW d 104, kg	246.83	241.48	2.82	0.19	244.44	243.87	2.82	0.89
BW d 135, kg	215.71	219.00	2.72	0.40	216.31	218.39	2.67	0.57
BW Mean, kg	226.82	224.78	1.69	0.40	225.74	225.86	1.69	0.96
BW Gain 1 (d 30 to 70), kg	10.64	9.94	1.92	0.80	10.71	9.88	1.92	0.76
BW Gain 2 (d 70 to 90), kg	4.96	3.27	0.93	0.20	3.99	4.24	0.93	0.85
BW Gain 3 (d 90 to 104), kg	19.58[a]	16.49[b]	0.95	0.03	18.65	17.43	0.95	0.37
BW Total Gain, kg	35.71	30.78	2.80	0.22	33.31	33.18	2.80	0.97
BW Loss, kg	-31.18	-23.32	2.93	0.06	-27.92	-26.58	2.86	0.73
BF Mean, cm	1.76	1.81	0.03	0.25	1.82	1.76	0.03	0.20
BCS, 1-5	3.00	2.98	3.60	0.52	3.00	2.98	3.60	0.55

[a,b] Means within a row with different superscripts differ ($P \leq 0.05$).

Table B.2 Main effects of diet and feeding stall length on productivity (Least Square Means)

	Diet				Feeding Stall Length			
Item	Midds-Hulls	DDGS-GM	SE	P-value	Long	Short	SE	P-value
No. Born	13.86	13.07	0.67	0.41	13.59	13.33	0.67	0.79
No. Born Alive	11.99	11.66	0.56	0.68	12.1	11.55	0.56	0.50
No. Males	5.82	5.84	0.41	0.97	5.55	6.12	0.41	0.32
No. Females	5.83	5.24	0.41	0.31	6.05	5.02	0.41	0.08
No. Stillborns	1.67	1.27	0.35	0.42	1.34	1.6	0.35	0.59
No. Mummified	0.2	0.14	0.08	0.62	0.16	0.18	0.08	0.87
No. Laid On	0.68	0.78	0.2	0.77	0.82	0.64	0.2	0.31
No. Euthanized	0.7	0.82	0.19	0.60	1.07[a]	0.46[b]	0.19	0.03
No. Total Mortality	3.25	3.01	0.45	0.55	3.38	2.88	0.45	0.40
Litter Wt., kg	19.12	19.92	0.98	0.56	20.18	18.86	0.98	0.34
Adj. Litter Wt., kg	18.85	20.28	0.64	0.13	19.96	19.16	0.64	0.38
No. Weaned	10.44	10.08	0.37	0.49	10.06	10.46	0.37	0.44
Litter Wean Wt., kg	69.93	70.74	2.6	0.83	70.81	69.85	2.6	0.80
Adj. Litter Wean Wt., kg	68.91	71.96	1.28	0.10	72.17	68.7	1.28	0.06
Avg. Piglet Wean Wt., kg	6.75	7.05	0.13	0.12	7.07	6.73	0.13	0.07

[a,b] Means within a row with different superscripts differ ($P \leq 0.05$).

Table B.3 Main effects of diet and feeding stall length on body lesion scores (Least Square Means)

	Diet				Feeding Stall Length			
Item	Midds-Hulls	DDGS-GM	SE	P-value	Long	Short	SE	P-value
Total Severity	26.65	26.53	0.59	0.86	29.15[c]	24.03[d]	0.6	<.0001
Head, 0-7	1.72	1.76	0.16	0.83	1.90[a]	1.58[b]	0.16	0.05
Ears, 0-7	1.24	1.47	0.14	0.11	1.33	1.39	0.14	0.69
Neck, 0-7	3.89	3.62	0.18	0.15	4.17[c]	3.34[d]	0.18	<.0001
Shoulders, 0-7	4.42	4.56	0.17	0.46	4.58	4.4	0.17	0.31
Side, 0-7	4.39	4.49	0.18	0.61	4.55	4.33	0.18	0.25
Back, 0-7	1.87	1.84	0.16	0.82	2.61[c]	1.10[d]	0.16	<.0001
Udder, 0-7	0.83	0.87	0.11	0.77	0.95	0.75	0.11	0.10
Rear, 0-7	2.21	2.26	0.17	0.80	3.15[c]	1.33[d]	0.17	<.0001
Vulva, 0-7	0.53[a]	0.25[b]	0.09	0.003	0.51[a]	0.27[b]	0.09	0.009
Front Legs, 0-7	1.12[a]	0.78[b]	0.12	0.01	1.11[a]	0.79[b]	0.12	0.02
Hind Legs, 0-7	4.53	4.36	0.18	0.38	5.03[c]	3.86[d]	0.18	<.0001

[a,b] Means within a row with different superscripts differ ($P \leq 0.05$) and **[c,d]** differ ($P \leq 0.001$).

Table B.4 Main effects of diet and feeding stall length on behaviors registered during feedings (Least Square Means)

	Diet				Feeding Stall Length			
Behavior	Midds-Hulls	DDGS-GM	SE	P-value	Long	Short	SE	P-value
Total Aggressive Encounters	19.88	20.63	2.01	0.68	14.69[d]	25.81[c]	2.01	<.0001
Total Displacements	7.69	12.19	1.51	0.29	2.41[d]	17.47[c]	1.51	<.0001
AE:Disp	5.07[a]	2.91[b]	0.56	0.01	6.32[c]	1.66[d]	0.56	<.0001
No. AE to SUB	7.53[a]	5.28[b]	0.81	0.05	5.66	7.16	0.81	0.19
No. Displacements to SUB	2.88	2.91	0.60	0.19	1.06[d]	4.72[c]	0.6	<.0001
No. AE by DOM	8.97	9.63	1.12	0.68	6.63[b]	11.97[a]	1.12	0.002
No. Displacements by DOM	4.72	6.13	0.82	0.23	1.09[d]	9.75[c]	0.82	<.0001
No. AE by DOM to SUB	3.66	2.56	0.51	0.11	2.88	3.34	0.51	0.35
No. Disp by DOM to SUB	1.75	1.25	0.36	0.33	0.63[b]	2.38[a]	0.36	0.001

[a,b] Means within a row with different superscripts differ ($P \leq 0.05$) and [c,d] differ ($P \leq 0.001$).

Table B.5 Main effects of diet and feeding stall length on immune and endocrine (Least Square Means)

	Diet				Feeding Stall Length			
Item	Midds-Hulls	DDGS-GM	SE	P-value	Long	Short	SE	P-value
Total WBC, 10^7	6.70[b]	7.34[a]	0.3	0.05	6.88	7.16	0.23	0.37
Lymphocyte, 10^7	4.24	4.23	0.28	0.88	4.42	4.05	0.28	0.31
Neutrophil, 10^7	21.41	20.59	0.85	0.70	22.14[a]	19.86[b]	0.84	0.05
Lymphocytes, %	44.94	46.71	0.96	0.19	47.30[a]	44.35[b]	0.96	0.03
Monocytes, %	2.35	1.97	0.17	0.09	2.04	2.27	0.16	0.44
Eosinophils, %	5.13	4.65	0.35	0.32	4.72	5.06	0.35	0.30
Segmented Neutrophils, %	0.78	0.60	0.12	0.11	0.54	0.84	0.12	0.06
Banded Neutrophils, %	46.75	46.05	1.03	0.63	45.38	47.43	1.03	0.16
Total Neutrophils, %	47.53	46.65	1.03	0.54	45.92	48.27	1.03	0.11
Neutrophil-to-Lymphoycte Ratio	1.38	1.24	0.07	0.18	1.22	1.39	0.07	0.09
ConA Proliferation, 2.0	1.01	1.01	0.01	0.95	1.01	1.01	0.01	0.56
ConA Proliferation, 20.0	1.05[a]	1.01[b]	0.01	0.02	1.03	1.03	0.01	0.79
LPS Proliferation, 5.0	1.09[a]	1.05[b]	0.01	0.04	1.07	1.07	0.01	0.81
LPS Proliferation, 50.0	1.14	1.09	0.02	0.23	1.11	1.12	0.02	0.66
Cortisol, ng/mL	15.76	15.31	0.83	0.55	14.96	16.11	0.83	0.33
IL-12, pg/mL	59.08	62.10	7.11	0.58	61.96	59.23	7.11	0.59
Blood Glucose, mg/dL	68.30	68.06	0.66	0.80	70.72[c]	66.37[d]	0.45	<.0001

[a,b] Means within a row with different superscripts differ ($P \leq 0.05$) and **[c,d]** differ ($P \leq 0.001$).

Table B.6 Main effects of diet and feeding stall length on behaviors (Least Square Means)

	Diet				Feeding Stall Length			
Behavior	Midds-Hulls	DDGS-GM	SE	P-value	Long	Short	SE	P-value
Stand								
Percentage, %	34.39	33.77	2.59	0.80	26.15[b]	32.38[a]	1.5	0.0002
Frequency, no.	542	222			360	372		
Sit								
Percentage, %	2.39[b]	6.10[a]	1.06	0.01	3.15	3.29	0.61	0.39
Frequency, no.	53	31			42	38		
Lay								
Percentage, %	11.08	10.76	1.79	0.73	6.69[b]	11.35[a]	1.09	0.0002
Frequency, no.	158	75			90	141		
ONF								
Percentage, %	20.73	20.66	2.56	0.90	30.46[a]	26.23[b]	1.51	<.0001
Frequency, no.	432	195			327	264		
Sham Chew								
Percentage, %	15.50	17.67	2.14	0.41	18.78	17.10	1.25	0.39
Frequency, no.	222	183			222	173		
Eat								
Percentage, %	11.74[a]	7.25[b]	1.41	0.02	10.99[c]	5.12[d]	0.86	<.0001
Frequency, no.	159	47			138	52		
Drink								
Percentage, %	3.70	3.86	1.14	0.92	3.51	4.24	0.66	0.70
Frequency, no.	64	31			43	52		
Locomotion								
Percentage, %	0.16	-0.23	0.33	0.37	0.28	0.28	0.19	0.46
Frequency, no.	7	1			4	4		

[a,b] Means within a row with different superscripts differ ($P \leq 0.05$) and [c,d] differ ($P \leq 0.001$).